THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME VII — APRIL 1898 — NUMBER 4

ON THE SPECTRUM OF HYDROGEN IN THE NEBULÆ.

By J. Scheiner.

The spectrum of hydrogen in the nebulæ differs, as is well known, from that obtained with Geissler tubes in this respect: that while under certain conditions $H\beta$ may be well seen, the $H\alpha$ (C) line can scarcely be detected or may be invisible, whereas in the spectrum of hydrogen tubes $H\alpha$ generally appears brighter than $H\beta$ (F). In only one nebula (*G. C.* 4390) was $H\alpha$ observed by Keeler, and it was very faint. It was long ago pointed out that by reduction of intensity the hydrogen spectrum could be reduced to the line $H\beta$ in the greenish blue. Thus in 1868 Lockyer and Frankland[1] showed that under certain conditions of temperature and pressure the hydrogen spectrum reduces to the line $H\beta$, but more precise data as to the nature of these conditions are wanting. The same year Huggins[2] showed that by weakening the intensity, the nitrogen spectrum could be reduced to a single line in the green, and, what it is here important to note, that this was effected by a purely subjective weakening, produced by the absorption of neutral tinted glass or by increasing the distance of the Geissler

[1] *Proc. Roy. Soc.*, **17**, 454.
[2] *Phil. Trans.*, 1868, 544.

tubes. Huggins thereby arrived at the following important conclusion: "It is obvious that if the spectrum of hydrogen were (likewise) reduced in intensity the line in the blue would remain visible after the line in the red and the lines more refrangible than F had become too feeble to affect the eye." The accuracy of Huggins' conjecture was later (1880) established by the direct observations of Fievez. It is consequently made very probable that the cause of the difficulty in seeing $H\alpha$ in the nebulæ is purely physiological, that is, it is an example of the Purkinje phenomenon. Nevertheless, this explanation does not appear to have been generally accepted, for quite recently Keeler,[1] in his beautiful investigation of the spectra of the nebulæ, expressed the opinion that because of the above mentioned peculiarity of the hydrogen spectrum the temperature of incandescence of the nebulæ must be very high. And quite recently Runge[2] has deduced important physical conclusions from this phenomenon.

It therefore seemed desirable to investigate the question of the luminosity of hydrogen in the nebulæ somewhat more closely, and to determine, by introducing circumstances approximating to those under which the nebulæ emit their light, whether objective changes of the character above referred to can be produced in the spectrum of hydrogen in the attenuated state, or whether the subjective weakening of the light is the determining factor, and if so to what extent.

The radiation of the nebulæ in space takes place under two conditions, which can be only approximately fulfilled in the laboratory. In the first place the gases are without doubt extremely attenuated, the molecular motions are exceedingly feeble, and the considerable brightness is due merely to the enormous thickness of the luminous strata (many millions of kilometers); and in the second place the emission takes place at an external temperature which can differ but little from absolute zero.

In reference to the first condition we have at hand a number

[1] *Publ. of Lick Obs.*, 1894.

[2] *A. N.*, No. 3471.

of investigations and experiments. In wide tubes excited by feeble electric discharges the hydrogen lines may be observed to vanish completely, while with thicker strata — obtained by looking lengthwise through the tubes — they again appear. Thereby, as was stated above, $H\alpha$ first disappears, and then $H\beta$. With reversed conditions the order of visibility is also reversed.

Investigations on the possible changes of the spectra of gases by lowering the external temperature were carried out by Koch[1] in 1889. He used wide Geissler tubes which were excited by means of a strong induction coil, at a temperature between —80° and —100° C. (obtained by mixing solid carbonic acid and ether), but could not detect any change whatever in the spectrum. Since it is now comparatively easy to obtain temperatures as low as —200° with liquefied air, the opportunity seemed to me to be favorable to extend the researches of Koch, and at the same time to excite the luminosity, not by the induced current itself, but by electric waves, since thereby a much smaller increase of the surrounding temperature is produced.

The considerable quantity of liquefied air necessary for the investigation was obtained by the friendly interest of Dr. Spies, of the Urania Institution in Berlin, who likewise gave me his kind assistance in carrying out the investigations themselves. As a receptacle for the liquefied air, into which the Geissler tubes were directly introduced, a glass vessel with double walls was used, the space between the two walls of which was exhausted as far as possible. This arrangement is necessary, for otherwise the exterior of the vessel will immediately be so thickly covered with frost as to make any observation impossible. Even then, when the outside glass wall is cooled merely by outward radiation, a strong deposit of frost is formed. The temperature of the outer glass envelope is, however, above the freezing point of alcohol, so that by washing with alcohol the frost can be removed. The tubes were excited in the field of

[1] *Wied. Ann.*, 38.

a Tesla high-tension transformer. Their luminosity was then quite weak, so that the hydrogen lines could just be recognized. No difference in the relative or absolute intensity of the hydrogen lines of the cold tubes, compared with the lines seen under the usual circumstances, could be detected, even when, in order to avoid raising the temperature by the radiation of the glowing gas itself, the excitation of the Tesla field was effected by a single spark, the spectrum being then observed as it momentarily flashed into view. Inasmuch as the space over the liquefied air was continually exhausted by means of an air-pump during the investigation, the temperature of the space surrounding the hydrogen could not have been higher than —200° C. in the case of a flash produced by a single spark. These investigations therefore confirm the earlier conclusions of Koch and lead to the further result that *the spectrum of hydrogen does not change when the surrounding temperature is reduced as low as —200° C.* (so far as the temperature can be ascertained without special measurements). This temperature approaches, at least, the absolute zero —273°, and it may therefore be stated as very probable that changes in the intensities of the hydrogen lines do not occur in any case when the external temperature is reduced.

This conclusion also fully agrees with the modern views concerning the luminosity of gases, according to which the radiations which produce line-spectra arise from disturbances within the individual molecules, and are therefore independent of the surrounding temperature.

I now pass to an investigation of the physiological disappearance of the $H\alpha$ line; in order, however, to obtain results free from the possibility of doubt, it was first necessary to determine whether the earlier disappearance of the $H\alpha$ line, when the intensity is objectively reduced by diminishing the electric excitement, is not at least partially caused by an actual change in the relative intensities of $H\alpha$ and $H\beta$. For this purpose I compared the intensities of $H\alpha$ and $H\beta$ with the intensities of the corresponding wave-lengths in the spectrum of a petroleum flame, by means of a spectrophotometer. With two different

Geissler tubes, I thus obtained for strong induction currents and for weak electric waves the following figures, which indicate how many times the brightness of the red in the spectrum of the petroleum flame appeared to exceed that of $H\alpha$ when the intensity of $H\beta$ was placed equal to that of the corresponding wave-length in the continuous spectrum :

Induction Current	Electric Waves
3.4	4.0
2.1	3.3
2.8	3.4
2.7	2.1
2.8	3.2

These figures are means of four settings, which, however, owing to the difficulty of such observations, are rather uncertain, so that the final values 2.8 and 3.2 are to be regarded as fairly accordant. Thus it appears that in the case of the objective weakening produced in these experiments, which was as much as one-fiftieth part of the original intensity, real changes of the relative intensities of $H\alpha$ to $H\beta$ were not produced, and hence the figures which follow are the expression of purely physiological phenomena.

For measuring the different reductions of intensity, by means of which the hydrogen lines are brought to the vanishing point, a spectrophotometer, or, in fact, any compound spectroscope, could not be used, because in such an instrument the faint lines could no longer be seen. The following simple arrangement was therefore used. The Geissler tube was set up at the distance of distinct vision (or at a distance somewhat greater), and viewed with a direct-vision system of prisms, the capillary bore of the tube serving as a slit. Between the tube and the prism-system two Nicol prisms were introduced, one of which could be turned and its angular displacement measured. By turning this prism the hydrogen lines could be made to vanish.

In all cases, even in that of feeble excitation in wide capillaries, the $H\alpha$ line appeared to me always brighter than the $H\beta$

line. Then on weakening the light, there occurred, at a certain intensity, an apparent equality of the two lines, after which *Ha* disappeared and then *Hβ*.

The determination of the moment of disappearance is naturally quite uncertain; however, the figures obtained in a single series of observations agree fairly well. The marked difference between the two series observed by me may be due in part to a real difference in the sensitiveness of the eye; but they are principally to be ascribed to differences in the experimental conditions, and especially to differences in the apparent width of the lines, which gave rise to marked changes in the perception of the lines; the more accurate investigation of this latter effect is of only physiological interest. These are closely related to the recently published physiological investigations of Lummer,[1] and it is necessary to note here only this much—that for my eyes the color sensitiveness to the red remains up to the point of complete disappearance, while in the case of the *Hβ* line previous to vanishing sensitiveness to the blue-green ceases, and the line appears merely gray.

The following table contains the ratios of the intensities of the *Ha* and *Hβ* lines, at the moment of disappearance, obtained from numerous observations. The numbers thus indicate how many times, after *Ha* had vanished, the light had to be weakened in order to cause the disappearance of *Hβ*.

		Scheiner		Hartmann
		I	II	I
Wide capillary,	Strong induction current	35.4	14.2	30.0
	electric waves	8.1	8.1	8.0
Medium capillary,	Strong	31.1	7.8	28.7
	weaker induction current	15.1	19.3	....
	electric waves	13.0	10.6	24.9
Narrow capillary,	Electric waves	18.1	....	27.6

The above results show that, for Dr. Hartmann as well as for myself, at least an eightfold weakening of the light is

[1] "Ueber Graugluth und Rothgluth," *Wied. Ann.*, 62.

required, in order to cause $H\beta$ to disappear after $H\alpha$ has vanished. Under some circumstances, however, this amount may be as much as thirty times.

Of special interest are some observations which Professor H. C. Vogel kindly made with a tube excited by weak induction currents, because his eye is but feebly sensitive to the red, while it is remarkably sensitive far out into the ultra-violet.

The value for the relative vanishing intensities of $H\alpha$ and $H\beta$ is increased in the case of Herr Vogel to five times the maximum value obtained by myself, namely, to 150, whereas for the disappearance of the $H\gamma$ line the corresponding number is only one-fourth of mine.

As an entirely independent confirmation of the values obtained I finally made the following experiment. In the field of the spectrophotometer were cut out, by means of the ocular slit, at the position of the $H\alpha$ and $H\beta$ lines in the continuous spectrum of the petroleum flame, fine artificial lines, the appearance of which precisely resembled that of the hydrogen lines with a narrow capillary tube. When weakened, precisely the same phenomena appeared as in the case of the actual hydrogen lines. The value obtained for the above ratio was 29.2.

I may add that the apparent equality of $H\alpha$ and $H\beta$ for my eye takes place at intensities ranging in the different experiments from 2 to 10 times the intensities corresponding to the vanishing point of $H\alpha$.

Now since in all the experiments I have described the $H\beta$ line was considerably brighter at the vanishing of $H\alpha$ than I have ever observed it in the spectrum of the nebulæ, the following result is established: The absence of the $H\alpha$ line in the hydrogen spectrum of the nebulæ is due to physiological causes, and it is consequently not permissible to deduce from this peculiarity of the hydrogen spectrum in the nebulæ any conclusion whatever concerning the physical conditions under which the light-emission of these celestial bodies takes place. Whether certain nebulæ may not prove to be exceptions to this rule is to

be left an open question; it is certainly not impossible that such may be the case.

It is evident that strongly marked physiological peculiarities of our eyes, such as the one under consideration, are also of importance in many other kinds of astronomical observations. Although they have long been well known, they have seldom received due consideration. I will here mention only the systematic differences between determinations of magnitudes of the bright and faint red stars, to which Herr Wilsing[1] called attention some years ago, and to the differences in the relative intensity of the lines of the nebulæ, which have been observed in differently bright portions of the nebula in Orion by various observers. Although in the latter case the lines in question differ but slightly in wave-length, their brightness is so close to the limit of visibility that great differences in relative intensity, sufficient to cause a complete apparent reversal of the order of brightness, may be produced.

ASTROPHYSICAL OBSERVATORY, POTSDAM,
January 1898.

[1] *A. N.*, **112**, 280.

ON THE LEVEL OF SUN-SPOTS AND THE CAUSE OF THEIR DARKNESS.

By A. L. CORTIE, S. J.

IN the number of the ASTROPHYSICAL JOURNAL for August 1897 Professor Riccò has published a table, formed from the drawings of Sun-spots made during the period 1881–1892 at Palermo and Catania, which supports the depression theory of the level of Sun-spots first advocated by Dr. Wilson. In view of the discussion which has been raised on this subject, it might be well to compare with Professor Riccò's table the results deduced by Father Sidgreaves from the Stonyhurst drawings made during the same period. The number of days on which the Sun was observed at the Italian stations during the eleven years was 3451, at Stonyhurst 2597. The drawings made by Professor Riccò are to a scale more than twice that of the Stonyhurst series, the diameters of the projected images of the Sun being 22.44 and 10.5 inches respectively. The smaller scale, however, is amply sufficient for the purposes of the discussion as to their bearing on the validity of the depression theory of the level of Sun-spots. Indeed, they are to be preferred to large scale drawings, as the tremors introduced into projection pictures of the Sun by magnification render accuracy of delineation somewhat difficult. This opinion based on experience is also subscribed to by Professor Frank W. Very in his paper on "Heliographic Positions" (ASTROPHYSICAL JOURNAL, **6**, 256, October 1897). Moreover, comparing these drawings with those which are occasionally made here on a scale of thirty inches to the solar diameter, no discordance or contradiction has ever been detected. Nevertheless it must be borne in mind that the presumably purer Italian sky would allow of greater magnifications being more safely employed than in England. Professor Riccò has selected 185 drawings of spots from his 3451 Sun pictures as admissible for the study of the question. The same

proportion would give 139 as the number which might be expected to be chosen from the 2597 Stonyhurst pictures. The number of different spots actually chosen by Father Sidgreaves was 126, giving 163 test cases at either or both limbs. Hence we may infer that the principles which guided both observers in the exclusion of unsuitable cases were practically identical. There is, however, one particular in which they have not agreed. For in Professor Riccò's table 36 cases are quoted as neutral, or cases in which the penumbra was symmetrical and of equal width on either side of the umbra when the spots were near the limb. But such cases would have been reckoned as against the Wilsonian hypothesis by Father Sidgreaves. And rightly so; for by the hypothesis, when a spot is near the limb the penumbra ought to be wider towards the limb. If it is not wider but equal on both sides of the umbra then the case is against the Wilsonian theory. Again, Professor Riccò writes: "Greater weight must be given to the still more significant cases of spots near the Sun's limb, the penumbra of which, conforming to the appearance of a cavity seen in perspective, is invisible on the side opposite the limb. I have found twenty-three cases of this sort in eleven years, and only one contradictory case." Why such cases should be more significant than that, for instance, of the large round spot of June 1887, which is reproduced in Plate 7 of the *Memoirs R. A. S.*, **49**, illustrating Father Perry's paper on "Photographs and Drawings of the Sun," and which indicates the existence rather of a mountain than of a cavity on the solar limb, it is difficult to understand. Or why more significant than those numerous cases of spots near the limb in which the penumbra in the direction of rotation has vanished altogether, leaving the umbra as a more or less thick line with a fringe of penumbra N. and S.? Such cases can be frequently observed and attention has already been called to their existence by Professor Spörer. In this connection, too, it may be well to recall to mind that Wilson demanded that the umbra of a deep spot should be lost to view altogether at 17″ from the limb, while for less degrees of depth he demands extinction of the umbra at 9″, 5″, and 3″.

Without supposing the spots to be as deeply cavernous as Wilson imagined them to be, yet the umbra might be expected to disappear when the spots are very near the limb, while exactly the contrary obtains. The umbra very rarely disappears even at positions right up to the limb, while frequently the penumbra on both sides of the umbra cannot be seen.

One fact worthy of notice, indicated by both the Italian and the Stonyhurst results, is that the number of symmetrical spots was much larger in the years 1881–1886 than in the latter half of the selected period. It will be remembered by solar observers that the maximum of 1882–1883 was of a protracted nature, the solar activity continuing unabated until the autumn of 1886, when the Sun became quiescent. The following table combines the results both for Catania and Stonyhurst, omitting the column of neutral cases as originally (*loc. cit.*) given by Professor Riccò.

PENUMBRA OF REGULAR SPOTS.

Year	Favorable to Wilson		Unfavorable to Wilson	
	Catania	Stonyhurst	Catania	Stonyhurst
1881	28	3	0	6
1882	16	5	7	12
1883	19	6	2	21
1884	22	8	5	28
1885	15	6	1	19
1886	10	6	0	16
1887	7	4	0	6
1888	0	0	1	4
1889	1	1	0	2
1890	2	0	1	0
1891	..	1	..	3
1892	11	2	1	4
Totals	131	42	18	121

From the table we deduce the proportion of cases favorable and unfavorable to the Wilsonian hypothesis:

	Favorable	Unfavorable
Catania,	7.3	1
Stonyhurst,	0.3	1

If we reckon cases in which the penumbra was symmetrical about the umbra when the spots were near the limb as unfavorable, as it seems to the writer they ought to be reckoned, then the Catania results would give the proportion

favorable : unfavorable :: 2.4 : 1.

But even so the discrepancy of the columns is so great that it is difficult to subscribe to the conclusion advocated by Professor Riccò; "it must, therefore, be admitted that the spots are cavities, *i. e.*, breaks or openings in the photospheric layer." Moreover, the Catania results themselves show that some 14 in every 100 spots are elevations above the photosphere. Therefore, not all spots are cavities, and at least some spots, even judging from the indications furnished by the estimated unequal breadths of the penumbra when near the limb, are situated above the photospheric level. But even allowing that the sides of the penumbra shelve downwards, no depression hypothesis has so far satisfactorily accounted for the numerous instances when the umbra, without any penumbra at all in the line of sight, or of such restricted amount that it cannot be detected even on large scale drawings, stands boldly out even up to the very limb of the Sun. On the contrary, it would be an exceptionally rare observation which could show a spot without the umbra visible at the limb. This fact is most important in framing any theory of the level of Sun-spots, and needs insisting upon. The ratio of the lateral breadths of the penumbra is relatively unimportant.

With regard to the cause of the darkness of spots, Professor Riccò seems to adopt the opinion that it is not attributable to the presence of substances which absorb on account of lower temperature. The spectra of Sun-spots, however, if we are to interpret them by the rules ordinarily applied to spectroscopic appearances, would indicate absorption as the cause of the darkness of Sun-spots. Even the continuous dark spectral band of a Sun-spot has in the region E to F been resolved into fine lines by both Young and Dunér, and in the region C to D, Young and the writer have independently detected the presence of identical

dark bands, of which the only satisfactory explanation seems to be the formation of compounds over a spot by a reduction of temperature. Again, the suggestion that Sun-spots may be particularly rich in ultra-violet light, advanced by Mr. Evershed, would seem to be negatived by the fact that, at least as far as selective absorption is concerned, the richest field for observing the characteristic phenomena of Sun-spot spectra is to be found at the opposite end of the spectrum. Beyond the reversal of H and K, photographs of Sun-spot spectra in the violet and ultra-violet regions are comparatively, if not entirely, wanting in details.

Another point worthy of notice in this discussion as to the level of Sun-spots, is that the results derived from a study of spots when near the limbs concern only regular spots, which are a very small proportion of all the spots observed, in Professor Riccò's results 185 in 3324 spots. Even if the phenomena of unequal penumbral width should indicate depression in every single case studied, which is far from being the case, yet it is not a logical sequence to draw the conclusion that all spots, at all times of their life histories, even when they are forming as scattered groups and separating into two main spots, as they generally do, are below the level of the photosphere. The only conclusion we are warranted in drawing is that Sun-spots, at the time in their life histories when they are round and quiescent, are below the level of the photosphere. Presumably the thermal researches of Frost, Langley, and Wilson were not made on this particular class of quiet, round spots, but on spots in general, whatever might be their form and structure. As a means of reconciling discordant results, I would suggest the possibility of a difference of level in Sun-spots at different periods of their life history.

In a note in the number of the JOURNAL for November 1897 Professor Hale discusses the subject of the appearance of spots when seen in transit across the Sun's limb, and also presents a very suggestive scheme of an ideal spot. In the whole course of the continuous observations of the Sun of the past seventeen

years, made at Stonyhurst, a transit of a spot across the limb has been seen but twice, and drawn on one of these occasions. The phenomenon is therefore very rarely observed, and deserves full discussion. The first case occurred on May 8, 1884, at 10:00 A.M., G. M. T. I quote the exact words of the observer, Mr. W. McKeon's notebook. "The new group of April 25 was now just appearing at the following limb as a large black spot. The spot was exactly on the limb, and when observed casually appeared to cause a notch in it. Upon close examination, however, with excellent definition the finest possible thread of light was seen behind the spot. Near the north of the spot I thought I could see a facula project out from the limb. The sky becoming hazy, I was unable to be absolutely certain of what I saw," *i. e.*, in regard to the projecting facula. The second case occurred on September 17 of the same year, when the penumbra on the following side of a large black spot was drawn when exactly on the limb. The umbra of the same spot was photographed on the limb some ten hours earlier in the famous photograph secured at Dehra Dun. The notched appearance presented in such photographs is attributed by the Rev. F. Howlett (*Monthly Notices*, **55**, No. 2, 1894) to "the lack of sufficient power in the already degraded light near the limb to depict the yet more degraded dusky spot." Father Sidgreaves (*Monthly Notices*, **55**, No. 5, 1895) fully accepts the evidence of the Indian plate—"the notching umbra is perfectly natural, of a strong silver deposit"—and contends that it "admits of no other explanation than that of a high elevation of the umbra." In this second case also, when drawn at Stonyhurst September 17, 3:34 P.M., G. M. T., "a very fine thread of light was discernible behind the spot" (observer's note). A careful study of the life histories of these two spots from the Stonyhurst drawings brings to light the following facts: On April 20 there was no sign of the first group, but it is shown on the drawing of the 22d. The faculæ round this new group were very scarce. In character it consisted of two main spots, the leader being the larger, with a few small spots between them, a common type of outburst. On

April 23 and 24 the observer again notes that faculæ were remarkably scarce and not bright about the group, which was now near the P. limb. It then transited the invisible hemisphere and was next seen as a notch on the F. limb on May 8. The drawing of May 9 shows it to be a single round black spot, and the note occurs that the faculæ were "rather faint near the large spot at the F. limb, and radiated from the spot, but not to any great distance." On May 10 an area of bright faculæ is drawn surrounding the spot. Between this and the 17th it continues as a round spot, with its encircling ring of faculæ. On the 17th there was a remarkable outburst of "veiled spots" in the region immediately following the spot. On May 21 it reaches the preceding limb, reappears again on June 6, still as a round spot, but much reduced in area, and on June 17 is drawn for a third time near the preceding limb. This is its last appearance. It was therefore a large, long-lived, and dense black spot.

If the cavernous hypothesis be correct we might reasonably have expected that a spot which caused a notch on the limb on May 8, would, on appearing on the visible hemisphere, have shown the penumbra of very unequal extent on either side of the umbra. When the spot was drawn on May 9 it was distant about $1'$ from the limb, and yet the breadth of the penumbra was almost equal on either side of the spot. It is difficult to judge to which side the preponderance should be given. It is catalogued as against the depression hypothesis. On May 20, when distant about $49''$ from the P. limb, it is decidedly against Wilson's cavernous theory. On June 6, at its next return, when distant $1'30''$ from the F. limb, the penumbra is again almost equal on either side of the umbra; allowing for foreshortening a rough measure gives an excess of only $0^{\circ}.2$ in favor of a depression. On the 16th it is near the opposite limb, $1'19''$ distant, and now it is unmistakably a depression. On the 17th, when distant $7'$ from the limb, it is a very small hazy line. It is a depression, therefore, when it is disappearing.

The life history of the second case, that of September 17, was of the same character as its predecessor. On September 6

a single minute umbral dot is seen ; on the 7th there are three dots amidst not very dense faculæ; on the 10th there is a scattered group of small spots. Next day the resolution into two main spots with the intervening group of small spots has commenced. For the three days, September 12–14, the two main spots grow greatly in area, amidst faculæ which cling to the spots and are not extensive. By the 15th the process of resolution is completed, and only the leader and rear spot of the group remain. The faculæ are few and tolerably compact, as is usual in newly formed groups. On September 16, as in the former case, we find it noted "faculæ scarce near the large new group approaching the P. limb," nor was there any great increase in the faculæ when on the 17th the leader of the group was in transit across the limb. The fact is noticeable that the penumbra on the following side of the umbra should have been seen at all in such a position. On October 2, when the group reappeared on the E. limb of the Sun, the faculæ radiating from the group were of considerable extent. The leading spot was the larger, and on October 3 the smaller began to break up and form into small spots, which by October 10 were a considerable number. This development was at the expense of the leader, which simultaneously became smaller, though remaining regular in outline. On October 13 and 14 the whole group was dying rapidly. At the next rotation the place of the group was occupied by a great area of faculæ. The first umbral dots, their rapid increase in area and formation into two spots with a companion group of small spots between them, the growth of the leader, the breaking up of the rearmost spot, the final dying out of either the isolated leader or the greatly reduced group, as mere penumbral patches, the compact and clinging faculæ in the early stages of the life of the group, its gradual extension and radiation in branched forms as the group grows older, and its final occupation of the total region of the spot outburst, is the usual sequence of phenomena in this type of spots. It was fully illustrated in the two groups under discussion.

With regard to the second example, on September 16, when

45″ from the limb and about to cause a notch, the penumbra, as in the first instance discussed, was by no means so unequal on either side of the umbra as it ought to have been had the spot been a cavity. However, the exact measure is difficult to give as the spot was broken. But on October 2, at its second appearance, when 20″ from the limb, if a rough outline drawing be correct it is not a cavity, the difference of the measures being about $0^\circ.7$ against the depression theory.

On referring to my notes of spectroscopic observations of Sun-spots, I find that I observed the spectrum of the first group on May 11, May 18, and June 12. I may state that I had hitherto not been aware that these observations, and those of the second group to be detailed below, were observations of the groups at different returns on the visible hemisphere. On May 11 the general absorption of the spot was so intense in the red as to almost mask the selective absorption, which was observed with difficulty. The lines, too, were more than usually widened in the penumbra. On May 18 the masking effect still continued, but the lines were not affected in the penumbra as on the 11th. On June 12 the spot was still very dark on the slit, and some iron lines were noted as being particularly affected in the spot. The spectrum of the second group was observed on September 11 and 12, and October 9. On September 11 some prominent calcium lines were observed as very much darkened in the umbra. On the 12th reversals and distortions of the C line were observed, and on October 9 the iron line at 6024.1 was not widened in the usual spindle-shaped manner, but was of the same width in both umbra and penumbra.

These two spots, then, which caused notches in the solar limb, by both visual and spectroscopic evidence, were long-lived dense black spots. Yet they were undoubtedly not deeply cavernous, and if not actually raised above the photospheric level during the greater portions of their lives, were the shallowest of depressions. To Lalande's objections against the cavernous theory of spots, drawn from Cassini's and de la Hire's observations of notches on the limb made by transit-

ing spots, Dr. Wilson replied (*Phil. Trans.*, **73**, 1783) that "a large shallow excavation, with the sloping sides or umbra (*i. e.*, penumbra) darker than common, may be more or less perceptible at the limb." The observations detailed above of the two spots observed on the limb in 1884 would certainly not negative, but would rather justify his contention, and in studying their life history I was independently, before consulting Wilson's paper, led to the same conclusion.

It would seem, then, that while many spots are above the photospheric level, and many below it, it is possible that individual spots are at different levels at different periods of their life histories, while notches at the limb are due to spots which are large black shallow depressions. The weight of spectroscopic evidence, too, favors the *opinion that the darkness is due to absorption*.

STONYHURST COLLEGE OBSERVATORY,
March 4, 1898.

SOURCES OF ERROR IN INVESTIGATIONS ON THE MOTION OF STARS IN THE LINE OF SIGHT.

By H. C. VOGEL.

THE *Bulletin Astronomique* for February 1898 (Vol. XV) contains an article by M. Deslandres entitled "Causes d'erreur dans la recherche des vitesses radiales des astres. Importance de l'erreur due aux variations de température. . Méthodes de correction." In this paper there are comments on certain of the methods of observation employed at Potsdam in determinations of the motion of stars in the line of sight, and M. Deslandres allows himself to make charges to which I must emphatically reply, since his suppositions are incorrect and are to be ascribed to the haste, which is wholly inexcusable in view of the gravity of the charges, with which M. Deslandres has read Vol. VII of the *Publicationen des Astrophysikalischen Observatoriums.* For the benefit of those who have read M. Deslandres' article, but may not have at hand my "Untersuchungen ueber die Eigenbewegung der Sterne im Visionsradius auf spectrographischen Wege," I will here consider somewhat more closely certain of the details referred to.

After a long introduction occupying a special section of his paper, M. Deslandres turns to a consideration of the methods of applying the comparison spectrum. He finds the plan employed by me of placing the Geissler tube at right angles to the slit, "very simple," but adds (p. 53) "but the pencils of the two sources to be compared are very different, and on account of this fact there may result a systematic error, which Vogel nevertheless has not examined in his great memoir." Now the simplicity of the method can hardly be regarded as a disadvantage; further, I am perfectly willing to admit the correctness of M. Deslandres' contention that the pencils from the two light-sources which are to be compared are different. But a simple consideration shows that the path of the light from the artificial light-source in the plane which passes at right angles to the slit through the

optical axis of the instrument, in which both the length of the spectrum and the expected displacement lie, is exactly the same as for the star. From this it appears that systematic errors are not to be expected if only the optical parts of the apparatus, when tested by themselves, are found to be free from defects. As a matter of fact, no error could be found in the previously undertaken test of the complete apparatus. (Vol. VII, p. 24.) The method, which I published over twenty-six years ago in the *Astronomische Nachrichten* and in the Bothkamp *Beobachtungen*, and gave in complete detail, with illustrations, in 1892, in Part I of Vol. VII of our Publications (beginning on p. 17), I cannot too highly commend, since it excludes the large accidental errors which easily enter in other methods, and which without careful attention may remain constant through long periods. It is, moreover, a simple matter for any one to convince himself by direct observation whether in my method systematic errors do or do not appear. I must, however, take decided exception to vague assertions made concerning it.

On p. 54 M. Deslandres remarks: "However, the photographic method contains a serious source of error which Vogel in fact mentions, but without according it due weight and without giving its value for the apparatus employed.[1] This error is the displacement of the spectra caused by changes of temperature during the exposure." I now continue my comments. In his paper in the *Annuaire* for 1891 M. Cornu could have referred only to the preliminary paper which I published on the Potsdam spectrographic observations, since Part I of Vol. VII of the *Publicationen des Astrophysikalischen Observatoriums* did not appear until 1892. But even in this paper, which was published in 1889 in the *Astronomische Nachrichten*, No. 2896, the influence of temperature was investigated (pp. 250–251), and M. Cornu, who at all events favored this article with a thorough examination, could not criticise a shortcoming which did not exist.

In the later publication I have devoted several pages to the

[1] "This error is not mentioned in M. Cornu's memoir on the subject (*Annuaire du Bureau des Longitudes*, 1891)."

great influence which temperature exercises on spectrographic observations. The special method of measurement employed for stars of Class II is the direct result of a consideration of the spectra as varied by temperature. But its importance can hardly have been fully appreciated by M. Deslandres, since in his own investigations he has dealt with only the larger and more palpable errors.

With reference to this last question I take the liberty of quoting from my own investigations (Vol. VII, Pt. 1, p. 24), at the same time remarking that the most important points raised here, together with the concluding sentence, may be found given in almost exactly the same words in the paper published in 1889, in No. 2896 of the *Astronomische Nachrichten*.

The influence that a variation of temperature during "the exposure exercises on the photograph is essentially caused by a change in the index of refraction of the prisms and by changes in the separate parts of the apparatus. As is well known, both the refracting angle and the dispersion of prisms are very decidedly affected by temperature, and in consequence of this change there occurs a displacement of the spectrum on the plate and a simultaneous lengthening or shortening of the spectrum. From this broadening of lines may result, which, however, if the variation of temperature is not very irregular, may exercise no injurious effect on the measures. Experience has shown that even in cases when the thermometer attached to the apparatus (not the temperature of the prisms) has changed 2° during an exposure of an hour, no noticeable effect could be observed. In the case of greater changes of temperature and longer exposures the effect becomes evident through the poor definition of the photograph. Certain experiments in which the apparatus was artificially heated have shown this appearance in a very marked way, but at the same time have demonstrated that well-enclosed prisms very slowly follow the temperature changes of the outer air. Expansion or contraction of the metal parts of the apparatus during the exposure may also cause a displacement of the plate; but this displacement will be extremely small, and it may

be assumed that neither this nor the changes in the optical parts of the apparatus can have any appreciable effect on the position of the lines of the comparison spectrum with reference to those of the star spectrum, if only, *as has always been the case in the observations*, the artificial light-source is employed during *the whole time of exposure*, or at *intervals which are symmetrical with reference to the middle of the exposure time*." This last sentence disposes of the criticism made by M. Deslandres (p. 58, line 13 from the bottom). He gives further clear evidence of the hasty manner in which he has read my article when he says: "Vogel does not give the ordinary time of exposure of the hydrogen tube employed." Further below he remarks, "the exposure of the comparison spectrum is *naturally* always made in the middle of the exposure of the star," and M. Deslandres is of the opinion that this procedure gives only a first approximation in allowing for the effect of temperature. In my own opinion it is not natural, but wholly wrong to expose the comparison spectrum only at the middle of the exposure time for the star, as follows from the concluding sentence of the long extract from my article which has been already quoted. Regarding the few observations with the iron spectrum, which are really to be considered only as investigations on the utility of a spectrum other than that of hydrogen, I remark in Vol. VII, p. 19 (below): "The exposure for the iron spectrum, which, as has already been mentioned, is very short, is given either at the beginning and the end of the exposure of the star spectrum or at the middle of the exposure. In the latter case the sharpness of the lines of the comparison spectrum affords *no evidence* regarding the unchanged condition of the apparatus during the much longer exposure on the star; on account of the simplicity of this procedure I have made the exposure on the artificial spectrum at the middle of the exposure of the star spectrum, but as in the case of the other photographs, I have employed as a check the hydrogen spectrum, which was exposed *during nearly the entire exposure time for the star*."

The method which M. Deslandres employs of photographing

on the plate several iron spectra at various distances from the star spectrum at the beginning, the middle, and the end of the exposure of the star spectrum, has also been practically tested by Mr. Newall (*Monthly Notices*, Vol. LXVII, No. 8). He employs not only the three iron spectra used by M. Deslandres, but four, two of which are on each side of the star spectrum.

I am unable to see any great advantage in this method; for there is little use in causing the changes which take place during the exposure of the star to be directly visible, if only one so arranges the observations that the changes can have no influence on the measures. This is the case when one employs my method, photographing the comparison spectrum immediately before and immediately after the spectrum of the star, and in such a way that in both instances, and naturally on both sides of the spectrum of the star, the lines lie as close as possible to this spectrum, and when no variation has occurred, are exactly superposed. Even if the comparison spectra are very narrow, in four exposures the outer ones lie so far from the spectrum of the star that the measures are rendered very difficult on account of the curvature of the spectral lines.

I believe that all the criticisms which M. Deslandres has directed against the Potsdam observations may now be regarded as completely disposed of.

I may remark in passing that I consider little advantage will follow from M. Deslandres' idea of surrounding the spectrograph with water for the purpose of protecting it from temperature changes, on account of the experience derived from the entirely similar experiments which I made ten years ago with Professor Scheiner, when in our preliminary investigations we were almost ready to doubt the possibility of obtaining valuable results on account of the marked effect of temperature on our apparatus. These experiments led to no important results, but they gave us a better knowledge of the peculiarities of the apparatus and led us to give them such consideration that finally observations of great precision resulted. What degree of precision was attained, not only for the small portion of the spec-

trum employed in determinations of motion, but also for the whole extent of the region included on the spectrogram, may be seen in Part II, Vol. VII, of the *Publicationen des Astrophysikalischen Observatoriums*, which was published in 1895, and with which M. Deslandres seems to be unfamiliar.

I have no occasion to deal further with M. Deslandres' article, as it contains, following the custom of the younger astrophysicists, nothing more than a number of suggestions regarding various forms of construction which, as they have not been tried in practice, are for the most part of very little value.

ASTROPHYSICAL OBSERVATORY,
Potsdam, February 28, 1898.

THE VARIATION OF SOLAR RADIATION.

By FRANK W. VERY.

THE measurement of the absolute value of solar radiation is so difficult, that for a long time an estimate of the solar constant prevailed, which was but little more than half of that now accepted; and there is, as yet, no definitely established doctrine as to the amount, or even as to the fact, of any change in this fundamental quantity, although presumably all astronomers would concede the probability of some small fluctuation in the so-called "constant," to say nothing of a progressive variation in the course of ages, which is not considered here.

Every direct measurement of solar radiation requires correction for instrumental errors and atmospheric absorption. The correction at sea-level, even under favorable circumstances, nearly equals the quantity directly indicated by the actinometer, and the absorptive quality of the terrestrial atmosphere fluctuates fortuitously, not only from day to day, but from minute to minute. Under these circumstances, refinements in actinometry are of small avail. Methods of measurement are already far in advance of other conditions of the problem which are beyond our control. It is evident that the possible fluctuations in the Sun's absolute radiative energy most intimately concern the science of meteorology, and it is possible that the problem will have to be solved entirely by meteorological methods.

There is at present but little unanimity of opinion as to the value of such methods. The fact that simultaneous weather conditions in different parts of the Earth are diverse, has appeared to some sufficient to make the determination of a connection between solar and terrestrial changes hopeless, while others have denied that there can be any connection under such circumstances. I cannot agree with these positions. The same cause produces opposite effects under varying concomitant conditions. Gravity which causes the fall of a stone, makes the balloon rise. The

prevailing methods of indiscriminate averaging in meteorology eliminate some of the most important factors. On the other hand, there is undoubtedly a tendency to coax results by the application of sorting methods which need to be warily handled, and should be, as far as possible, founded on rational considerations.

The aurora is the terrestrial phenomenon which exhibits the most intimate dependence upon solar changes. Tacchini[1] traces a connection between its appearance and chromospheric outbursts, and coincidences between remarkable auroras and extraordinary Sun-spots are frequent. Tacchini's opinion that "terrestrial auroras are more closely related to the phenomena of the chromosphere than to those of the spots" is perhaps rather conjectural, since we only know of the existence of prominences if they happen to occur when their locality is passing through a very limited zone at the Sun's limb. I should prefer to base estimates of solar activity on spectroheliographic studies of the entire visible surface, or upon the integrated area of Sun-spots, with the proviso that the appearance of large or rapidly changing prominences, together with marked distortions of the hydrogen lines in the spectrum of Sun-spots, or the breaking out of brilliant plumes and bridges in spot-groups with rapid changes of form, are presumably indices of much greater solar activities than those connected with mere magnitude of disturbed area. The latter is, nevertheless, more amenable to consistent and comparable numerical estimate.

It seems to have been fully established that auroras are more numerous and more brilliant in the latitude of the northern United States, or of northern Europe, at the time of maximum Sun-spot activity; but there is also evidence that still farther north the reverse of this is true. The fact, first established by Loomis, that auroras are not distributed uniformly over the polar regions, but occur most frequently in an oval belt, $10°$ to $20°$ wide, surrounding the magnetic pole, the longest diameter of the oval (some $55°$) extending in the direction of the eastern parts of North America and Asia, is to be supplemented by the further

[1] This JOURNAL, **1**, 211, March 1895.

fact that this belt fluctuates, attaining its greatest expansion, and contributing auroral displays to the lowest latitudes, in years of many Sun-spots, but contracting towards the magnetic pole when Sun-spots are few.

In the *Monthly Weather Review* for November 1896, Professor Abbe has given isobars for the level of 5000 meters altitude, and points out that at this altitude there is a permanent low of an oval form over the polar regions, having its longer axis directed to eastern North America and Asia. The diminished friction of air masses moving over the ocean, permits a more rapid replenishing of this permanent low from the side of the oceanic basins, which narrows the limits of the low from these sides, while the general eastward revolution of the atmosphere along the outer boundary of the high-level permanent low deflects its longer axis from the continental centers to their eastern margins. Professor Abbe points out that the storms of the temperate zone follow the margin of this high-level permanent low, with allowance for some fluctuation in its limits or in the position of its longer axis. A glance at Chart VII, in the publication mentioned, will show that the high-level isobar of sixteen inches defines the average winter storm-track somewhat closely.

Now I would suggest that the sixteen-inch isobaric boundary of this high-level permanent low is not far from the outer limit of Loomis' auroral zone, and that it is desirable to inquire whether the limits of the high-level low may not, like the auroral zone, vary with the Sun-spot cycle. Certain facts make me suspect that there is such a concomitant variation, but if must be established by more complete evidence. If there is such a variation, I believe we may be permitted to anticipate that the cause of this connection is somewhat as follows:

The Sun-spots are an evidence of exceptional overturnings in the solar atmosphere, and while themselves radiating less powerfully than the neighboring photosphere, the more active replenishing of the outer layers of the photosphere by intensely heated matter from below, probably increases the total radiation of the

Sun at the greatest Sun-spot manifestation. If so, the Earth's torrid and warm temperate zones, which occupy eight-tenths of the entire area of the spheroid, experience higher temperature and increased evaporation from the tropical oceans at this time. Large bodies of moist air are then brought into the higher latitudes, disturbing the equilibrium there and intensifying storms. Anti-cyclones will also be intensified at the same time as cyclones, so that while some regions are experiencing exceptional storms, others are enjoying uncommonly fine weather. Since, owing to the shallowness of the Earth's atmosphere, the interchange of warm and cold air in middle latitudes is mainly by alternating hot and cold waves, and since the warm air rises and proceeds on its journey to the poles as an upper current, while cold air from the poles presses down beneath it as a surface current, it follows that any increase of storm-intensity in middle latitudes lowers the general surface temperature there. We find that maximum Sun-spot years are about 2° F. colder, and have a barometric pressure 0.035 inch higher than minimum years in the Mississippi valley.[1] In central Europe, it appears from curves published in the *Meteorologische Zeitschrift* for November 1896 (Taf. XII), that the temperatures of maximum Sun-spot years are lower by from 1°.5 to 2°, although the turning points of the temperature curves are apt to lag a year or two behind the corresponding points of the solar curve.

As to the cause of the aurora, I suggest that it comes from polar air, electrified either by friction or by insolation, and kept from rapid discharge by its dryness, until it comes in contact with the moist air carried over it from the mid-latitude storm-belt. Over a wide zone on the poleward side of the storm-belt there is a quiescent brush-discharge of electricity in an upward direction, under the control of the magnetic lines of force as regards the general direction of the discharge, but only sufficiently intense to produce the typical argon fluorescence,[2] along

[1] *Monthly Weather Review*, January 1887, Hazen's Curve.

[2] Or perhaps it should be said "fluorescence of some argon compound" as suggested by BERTHELOT, *C. R.*, April 16 and June 24, 1895.

atmospheric strata, or through elevated air-streams, where water-vapor is relatively abundant.

Moisture-laden streaks, thrown up by great storms, may extend to higher levels than is commonly supposed, like the solar prominences projecting above the average chromospheric level; although after having been conducted along such moist filaments to the upper conductive regions of greater rarefaction, farther discharge may be easy through air entirely deprived of moisture; at any rate, there is good evidence that the aurora sometimes extends to altitudes of at least 500 miles, where there can be no assistance to the conductive process by water-vapor. The enlargement of the area of cold polar winds, if such enlargement can be proven to exist at Sun-spot maxima, would naturally force the belts of auroral discharge farther from the poles, and would largely explain the greater frequency of the aurora in middle latitudes at that time. It is possible, also, that the aurora may then be more brilliant on account of an intensifying of storms, but to prove this we need numerical estimates of storm-activity similar to those which have been attempted by the United States Weather Bureau for cold waves.

A recent aurora will serve very well to illustrate the hypothesis put forth here. At 7:15 P.M. (E. M. T.) Tuesday, March 15, 1898, an irregular luminous band, 20° to 30° wide, first visible about three-quarters of an hour earlier as a bright spot in the east, stretched entirely across the sky from E. N. E. to W. N. W., passing through the zenith at Providence. On the north side the light faded away indefinitely. Southward the band was sharply defined, reaching out huge tentacles, which at times stretched farther south than Orion. These great luminous projections, resembling swollen-tipped fingers of a gigantic hand, were somewhat equally spaced, and alternated with deep bays, cutting into the belt, with nearly semicircular margins, which, passing by continuous curvature into the edges of the tentacles, were occasionally bright and sharp on the north side, and pushed up straight columns converging by perspective towards the magnetic zenith; but, as a rule, the diffuse luminosity was quiescent.

Not so the individual members of the great series of slightly curved tentacular projections, of which there were eight or ten visible from horizon to horizon, becoming smaller in the distance, and both smaller and brighter in the east than in the west. These moved slowly from east to west, occupying about an hour in passing across the sky, new forms appearing in the east as the western ones vanished. Lower down, in the north, the appearance of folds of a hanging curtain, with momentaneous scintillation of vertical striae, appeared and disappeared several times; but the broad, quiescent, tentacular band, through which the brighter stars were visible, persisted for nearly an hour, receding northward very slowly. The air, which had been calm at first, began to move feebly from the south, and seemed to be pushing back the auroral arch. About 8 : 15 P.M., the south wind having become brisk, the arch receded more rapidly, and the northern sky suddenly changed, developing four or five irregular, broken, luminous belts, the breaks being possibly due to opaque clouds. A very brilliant display broke out in the northeast. For a short time the procession of moving columns appeared, passing from west to east. The whole sky was covered with patches of faint luminous haze, but without any quivering. Then the arches faded and receded towards the northern horizon. Other observers reported a final very bright column in the southeast at 9 : 15 P.M.

A less brilliant display had been seen on the previous evening, culminating at 9 : 45 P.M. in a double undulating arch of 10° to 20° altitude, sending up streamers as high as the North Star, and progressively brightening from east to west.

A group of Sun-spots was approaching the Sun's western limb on the 15th. The largest spot showed unmistakable signs of great activity and rapid change. Its four-cornered umbra indicated inrushes from as many sides.

Anti-cyclonic conditions and a cloudless sky prevailed on the 15th, but on the following morning altostratus, passing into stratus, covered the sky from the south. It seems a fair interpretation of these appearances to assume that on the evening of the 15th, the center of the anti-cyclone being northeast of my

station, the incipient south wind brought enough moisture into the lower atmosphere to start the upward brush-discharge from fresh volumes of electrified air successively farther and farther north, the vigor of the discharge being related to the velocity of the moisture-laden wind and to the previous strength of electrification. The slow westerly movement of the great luminous projections was perhaps due to an east wind in the upper air, preceding the cyclone then advancing from the west. The general and gradual movements of the aurora, occupying hours in their consummation, are presumably connected with atmospheric movements. The processional, darting, and quivering motions, being almost instantaneous, must, of course, be attributed to variations in the magnetic field, whether these variations are to be referred to irregular distribution of weather conditions, permitting electric brush-discharge at particular points, the local, partial discharge disturbing an otherwise uniform magnetic field, or whether the magnetic irregularity is of immediate cosmic origin. If the difficulties in the way of the cosmic theory could be successfully met, it would explain more satisfactorily the obvious connection between solar and auroral changes, and it must be admitted that the meteorological theory is also open to serious objections, inasmuch as conditions, apparently equally favorable for auroral display, do not develop any aurora in the absence of the peculiar solar conditions.

On the equatorial side of the mid-latitude storm-belt, it is quite probable that thunderstorms arise under conditions which equally give auroras on the poleward side. At any rate, Dr. Veeder's contention in favor of a simultaneous appearance of auroras in high latitudes, and thunderstorms in low latitudes at the approach of strong faculæ or Sun-spots to the Sun's eastern limb[1] is supported by a good deal of evidence, although I should say that not merely the advent of spots on the Sun's limb, but also their attainment of the central meridian, and, in general, any exceptionally sudden increments of solar activity, are conditions favorable to auroras and thunderstorms. The

[1] *Monthly Weather Review*, July 1887, p. 206.

point can be best examined by comparing terrestrial conditions before and after an exceptionally great Sun-spot which appears near the minimum epoch, when such occurrences are rare, with the corresponding conditions during the appearance of the Sun-spot.

Such occurrences were the following: In June 1889 (in the midst of a spot-minimum) we learn from the *Monthly Weather Review* that *no* Sun-spots were seen *until the 15th*, when a very large spot, attended by many small ones, appeared on the east limb. "Thunderstorms were reported in the greatest number of states and territories (thirty-six) on the 15th; in thirty-one on the 14th; in thirty on the 17th; in twenty-eight on the 16th; 20th, and 28th; in twenty-seven on the 29th; in twenty-six on the 21st," etc. Thunderstorms were therefore most numerous in this month at or near the time of the appearance of this spot, and they covered more than the average territory during its continuance. Auroras also were seen on the morning of the 15th (date of appearance of spot), and on the 20th, with a magnetic storm on the 21st (date of spot-passage over central solar meridian).

The same spot reappeared by solar rotation on the 12th of July, was central on the 18th, and passed off on the 24th. "Thunderstorms were reported in the greatest number of states and territories (thirty-nine) on the 13th and 14th," or again immediately after the reappearance of the spot, and they again covered more than the average territory during its visibility. Auroras were twice as frequent during the continuance of the spot, and the principal one (on the 20th) was two days after the spot's meridian passage.

Professor Bigelow[1] seems to think that solar magnetic influences are sufficient by themselves to produce not only terrestrial auroras, but also cold waves. The theory of Mr. E. B. Elliot[2] that the greater frequency of auroras near the equinoxes is due to the larger number of electric lines of force cut by the Earth

[1] *Monthly Weather Review*, March 1895.

[2] *Bull. Phil. Soc.*, 1, 45.

in its orbital motion at those seasons, and the more plausible magnetic influence of the neighboring Moon detected by Clayton[1] may also be mentioned, as well as Lord Kelvin's contention that immediate magnetic influence from a Sun-spot involves an enormous expenditure of energy, and in so far is improbable. I am not prepared to discuss the question from this side, but it seems to me possible that the Sun's radiant energy fluctuates more widely than is now generally admitted, and that it is capable of producing both the thermal and the electro-magnetic terrestrial changes, without invoking any direct magnetic effect, or at least that this explanation ought to be more thoroughly tested before it is abandoned.[2] If such an alternative hypothesis is warranted, it appears certain that variations of the intensity of solar radiation must occur in a single day sufficient to greatly increase terrestrial meteorological activities, and such fluctuations of the solar "constant" ought to be sought. I doubt whether they have yet been sought in the right way. The difficulties in the way of direct measurement have heretofore proved insuperable, but possibly they may be overcome. The meteorological method, however, has not been exhausted, and modifications in its application deserve trial. Most of our material comes from the temperate zones and is difficult to analyze. The fact that so large a part of the Earth is in lower latitudes than the average storm-belts, and that the greater part of this surface is oceanic, warns us that our mid-latitude storms are a mere fringe on the grander field of tropical atmospheric activities.

[1] *Am. Jour. Sci.*, (4) **5**, 81, February 1898.

[2] HIRN (*Constitution de l'espace céleste*, p. 247, Paris, 1889) has suggested that the solenoidal earth-currents, which are assumed to be the source of terrestrial magnetism, may originate thermo-electrically in the successive unequal warming of the periphery of the Earth by solar radiation. Any sudden variation in the solar constant must disturb the regularity of the flow, and give strong induction effects. M. Hirn, however, preferred the hypothesis of a solar electric surface-charge "whose intensity depends every moment on the phenomena which transpire within the star," and whose inductive action on the faces of the Earth, presented towards, and turned away from the Sun, combined with the shifting of these areas of induced electrification by the Earth's rotation, might produce earth-currents, whose exceptional variations are, in this case, attributable to sudden changes in the solar electric charge.

If temperature and humidity observations could be collated from the logs of vessels crossing the torrid zone, estimates of oceanic evaporation from day to day, combined with rainfall measures, might lead to the detection of the variation of solar radiation. We have the summaries of Buchan, but lack details. What is needed is some method of eliminating the superabundant variations in all meteorological elements, originating in telluric conditions, without also getting rid of the special solar term at the same time. For this purpose some parts of the torrid zone offer certain advantages. Comparing the barometer-curves of Port Darwin (lat. 12° 28′ S.) in North Australia, and Adelaide (lat. 34° 57′ S.) in South Australia, the tropical station exhibits an almost entire freedom from the barometric changes which, at the southern station, register the passage of every storm-center even at too great a distance to otherwise affect the weather. The temperatures at the tropical station are also remarkably steady, but are influenced by the direction of the wind. Specially favorable stations would seem to be those small islands in the tropical regions of the Pacific Ocean, famous for their steady trade winds, the islands themselves being too small to affect the result by their land conditions. The region of the permanent area of high barometer in the north Atlantic might answer, but the favorably situated Azores are rather larger and higher than we should wish, since the varying land conditions ought to be kept subordinate. A high mountain near the equator, such as the Boyden station on El Misti, might seem to be sufficiently isolated, but here we have a position lying on the boundary between arid and excessively moist regions, where fluctuations are to be anticipated according as the air is derived from one or the other source.

In the temperate zones the case is all but hopeless, the local variations are so large. By vast labor in the summation of a great many series, some slight residual may finally emerge which is really of solar significance, but the uncertainty of the result gives it little weight. It does not appear to be necessary that the sign of such temperate residual should agree with that

from the tropics. While higher tropical temperature produced by greater solar radiation must increase convection which may transfer extra heat to the temperate and polar zones, it is quite possible that certain regions may get more than their share of the returning polar winds concerned in the convection, and may have their temperatures lowered thereby. This, in fact, appears to be the case in the Upper Mississippi valley, and in Europe, as has been already stated.

The elimination of minor telluric fluctuations in the case of deeply buried earth-thermometers is to be noted, since it has given, in the case of the Edinburgh thermometers, an apparently authentic residual which coincides with the eleven-year Sun-spot period.

Great efforts have been made to detect some influence on the weather from the varying presentation of the Sun in its rotation. Clayton's storm-period of $3^d\ 2^h$, differs slightly from an even submultiple of the Sun's synodic rotation, derived from Sun-spot observations, and his storm-period of $7^d\ 6^h.43$ is no better in this respect, while both are quite as likely to be connected with the physical properties of the Earth's atmosphere and the dimensions of the Earth, as with any direct solar influence. Moreover, since different elements of the solar atmosphere have angular velocities which vary by at least 50 per cent., the choice of any period of solar rotation, as affecting solar radiation, unless governed by some marked property separable on independent grounds, is too conjectural to serve as a safe mathematical basis of computation.

Other suggested coincidences can hardly be regarded as better than complete failures. It seems rather ludicrous, when the best meteorologists can scarcely foretell the weather for more than a day in advance, to find scientists advocating periodic terms in weather changes, whose time they are prepared to state to the fourth or fifth decimal of a day, and attributed to the influence of solar rotation, in regard to which there might be selected values differing by many days without doing violence to any established principle.

While the possibility that there is some little-understood magnetic control of the weather, whose elucidation may lead to another "triumph of the fifth decimal place," cannot be denied, it seems at present more probable that solar radiation is the controlling influence in weather changes, and I would urge the collection of meteorological records from small islands in the trade-wind zones in mid-ocean, where local influences are small, as a possible means of determining variations of solar radiation. If such variations are found to synchronize at widely separated stations, and above all if increased oceanic tropical temperature immediately antedates sudden and otherwise inexplicable increments of storm-activity in temperate regions, a strong point will have been made in favor of solar thermal variability; while if the evidence is inconclusive, it may fix the limits within which it is permissible to assume a variation of solar radiation.

The hypothesis of diverse radiation from northern and southern solar hemispheres will account for one annual maximum and one minimum of solar radiation received by the Earth, or by any other planet which does not move in the plane of the Sun's equator. If the polar regions of the Sun radiate differently from its equatorial zone, or if there are zones of especially strong radiative power in Sun-spot latitudes, two annual maxima and two minima of solar radiation are possible; but since the Sun's equator is only inclined $7\frac{1}{4}^\circ$ to the ecliptic, no further multiplication of zones of unequal radiative power, capable of detection in the rounds of a body moving in the ecliptic, is probable.

The solar radiation is purely superficial. It is true that infra-red rays penetrate terrestrial clouds more readily than shorter waves, and doubtless emanate from greater depths in the photospheric cloudlike material; also, since the solar surface is very irregular, a large part of the photospheric rays are interstitial; but the radiation from the intensely heated layers below the photosphere is presumably discontinuous and of short wave-length, and thus incapable of penetrating the

luminous mist. Wilson and Fitzgerald[1] also suggest that refraction and reflection from irregular convection currents may play the part of an opaque mist. We have no means of deteımining the thickness of the cloudy shells of condensed vapor which sheath the streams of hot viscid gas from the solar depths, but since superimposed penumbral filaments exhibit no intensification at points of crossing, the cloud-thickness is of the same order as that of terrestrial clouds, and the precipitated mist sufficiently dense to protect the enclosed transparent gas from further cooling by radiation, as happens beneath terrestrial cloud-canopies. If there are terrestrial thermal fluctuations due to the direct influence of solar radiation, they probably originate either in the differential surface temperature of particular photospheric regions, which can only be maintained by differences in the circulatory mechanism by which heat is supplied to those areas, or else in the varying thickness or absorptive power of the Sun's atmosphere.

Sun-spots often recur in the same vicinity, and the viscosity of the deeper and hotter layers of solar substance is no doubt great enough to preserve local differences of temperature through long intervals.

Tacchini[2] states that during the years 1893 and 1894, and for the last three-quarters of 1892, prominences, faculæ, and spots were most frequent in the solar zones south of the equator. In the first quarter of 1895, the same observer[3] noted signs of change. Spots and faculæ continued to be more numerous in the southern zones, but prominences had become more frequent north of the equator, and in the second quarter of that year, the spots followed suit. In the last half of 1895,[4] faculæ and spots had their greatest development in the northern zones; but in the first half of 1896,[5] the preponderance of spots and faculæ was again south of the equator. In the second half of 1896,[6] with the exception of the great group of September 10 to 22, all

[1] This JOURNAL **5**, 101, February 1897.

[2] *Ibid.*, **2**, 26, June 1895.

[3] *Ibid.*, **2**, 225, October 1895.

[4] *Ibid.*, **3**, 252, April 1896.

[5] *Ibid.*, **4**, 182, October 1896.

[6] *Ibid.*, **5**, 159, March 1897.

activities were greater in the southern zones, and continued so during 1897.[1]

Now the south pole of the Sun inclines most towards the Earth on March 6, and the southern zones are more favorably presented during the half year from December 6 to June 4. Since this period includes that portion of the northern winter in which storms are most frequent, while the south-temperate zone is enjoying summer, we might anticipate that if regions where Sun-spots are numerous radiate more powerfully than others, the tropical and south-temperate zones should be warmer during the presentation of the Sun's south pole when solar activity predominates in the southern zones, while at the same time the north-temperate zone should be cooler than usual, owing to increased activity of terrestrial storms, and greater prevalence of cold waves. The hypothesis can only be fairly tested near the Sun-spot maximum, and the one which has just passed is exceptionally favorable for this purpose, both on account of a considerable discrepancy in the solar activity in northern and southern hemispheres, and because the solar phenomena have been carefully analyzed on a common plan in the summaries of Tacchini.

For comparison, I have tabulated the accumulated departures from the usual monthly mean temperatures for the twenty-one districts into which the Weather Bureau has divided the United States, taking the data from the *Monthly Weather Review*. The observations for each year have been divided into two groups: one for southern solar presentation from December to May inclusive; the other from June to November inclusive, corresponding to northern solar presentation. The year from December 1892 to November 1893, which was near the maximum of the Sun-spot period, is particularly noteworthy. For the entire country the departures were below normal in both halves of the year, but the six months of southern solar presentation were the colder by nearly two degrees Fahrenheit, in mean monthly departure. Only three regions out of the twenty-one

[1] This JOURNAL, **6**, 244, October 1897, and **7**, 170, March 1898.

showed a contrary sign from the general mean, and these were on the extreme southern border, namely, the South Pacific, South Plateau, and South Slope regions. The South Atlantic and Gulf States agreed with the rest of the country in showing lower temperature at the time of southern solar exposure, but by diminished amounts. The greatest negative departures were in North Dakota and the Upper Mississippi valley ; and, in general, the negative departures increased northward. There is every reason to suspect that south of the Tropic of Cancer, the departures may have been above normal, as hypothesis would indicate. No body of assorted information exists for the great tropical region in any way comparable with the admirable series of meteorological digests which Professor Abbe and his assistants have been placing at our disposal for central North America. It would be unfair to compare the readings from only a few tropical stations with so extensive a series, but as far as I have been able to find out, it appears that the tropical regions were experiencing exceptionally high temperature during this period of southern solar presentation, and the south-temperate zone shared in this influence to the extent of showing a very much smaller negative departure than during the time of northern solar presentation. In 1894 there was a smaller departure in the opposite direction in the United States, although the solar conditions remained about the same. This suggests that the very large negative departure of 1893 may have been partly due to an eccentric displacement of the pole of cold towards the American continent, and that this, by reaction, produced an opposite displacement in the following year. In this case a mean of the two years would more nearly express the true relation; but it may be safer to include the entire series of six years summarized in the following table, from which it appears that with a mean excess of 37.6 per cent. in southern solar activity, the six half years of south solar presentation gave a mean accumulated temperature departure from normal of $-0^{\circ}.683$ F. in the United States, the corresponding half years of north solar presentation giving $+0^{\circ}.045$ F.

	Accumulated semi-annual temperature-departures from normal											
	Dec. 1891 to May 1892	June to Nov. 1892	Dec. 1892 to May 1893	June to Nov. 1893	Dec 1893 to May 1894	June to Nov. 1894	Dec. 1894 to May 1895	June to Nov. 1895	Dec. 1895 to May 1896	June to Nov. 1896	Dec. 1896 to May 1897	June to Nov. 1897
New England	+9°.5	+2°.5	−16°.6	−1°.2	+4°.5	+2°.4	−3°.4	+2°.9	+1°.3	+2°.8	+2°.8	−0°.9
Mid. Atlantic States	+1 .1	−1 .1	−16 .1	−2 .0	+11 .7	+1 .9	−11 .8	+3 .3	+4 .6	+2 .8	+0 .2	+0 .7
South Atlantic States	−5 .0	−7 .4	−6 .9	−1 .3	+10 .1	−3 .5	−16 .6	+0 .7	+1 .2	+6 .3	−3 .6	+5 .0
Key West	−7 .2	−10 .0	−3 .0	−1 .5	+1 .7	−7 .7	−12 .2	−2 .8	−13 .6	+0 .9	−0 .4	−3 .2
Eastern Gulf	−7 .7	−5 .5	−4 .5	−1 .7	+6 .5	−5 .3	−17 .2	+0 .2	−3 .3	+6 .4	−2 .3	+8 .8
Western Gulf	−2 .1	−1 .7	−2 .4	−1 .4	+7 .7	−4 .0	−13 .9	−4 .3	+5 .8	+6 .5	+6 .0	+9 .7
Ohio Valley	−1 .4	−2 .0	−13 .5	+0 .7	+8 .7	+3 .1	−15 .4	+2 .7	+9 .9	+1 .6	−0 .6	+10 .5
Lower Lakes	+2 .5	+1 .8	−17 .2	+3 .6	+12 .3	+5 .8	−6 .7	+1 .1	+10 .0	−0 .8	+3 .0	+4 .7
Upper Lakes	+8 .9	+5 .2	−18 .3	+5 .8	+12 .2	+8 .5	+2 .8	+0 .6	+19 .2	−1 .5	+10 .4	+10 .4
North Dakota	+12 .9	+4 .8	−25 .1	+2 .3	+3 .9	+13 .1	+19 .9	−11 .5	+12 .2	−25 .2	+1 .1	+6 .4
Upper Mississippi Val.	+2 .4	−0 .3	−25 .1	+5 .0	+10 .1	+8 .5	+0 .4	+1 .1	+21 .2	−7 .7	+6 .0	+13 .2
Missouri Valley	+1 .4	+2 .9	−16 .0	+2 .9	+8 .3	+10 .2	+8 .9	−2 .9	+22 .1	−12 .6	+7 .0	+12 .8
Northern Slope	+1 .8	+3 .1	−14 .8	−3 .3	+4 .4	+9 .5	−0 .3	−10 .5	+8 .5	−15 .0	+10 .2	+1 .4
Middle Slope	−4 .4	+5 .3	−4 .6	+1 .9	+7 .7	+6 .0	−1 .7	−3 .9	+20 .6	−2 .3	+8 .5	+10 .5
Southern Slope	+0 .1	+4 .3	+5 .3	+6 .0	+10 .1	+1 .2	−13 .5	−7 .2	+15 .5	+4 .5	+4 .0	+4 .4
Southern Plateau	−9 .2	+1 .1	−5 .5	−5 .6	−8 .8	−0 .6	−1 .9	−5 .4	+0 .2	+4 .3	−1 .5	−0 .9
Middle Plateau	−15 .8	+4 .9	−20 .8	−1 .9	−2 .5	+0 .5	−9 .5	−7 .4	−5 .6	+2 .5	−0 .7	−0 .5
Northern Plateau	+7 .4	+3 .9	−22 .7	−13 .9	−1 .1	+4 .2	+7 .3	−6 .9	+9 .2	±0 .0	+13 .7	±0 .0
North Pacific Coast	+3 .6	−1 .0	−15 .4	−12 .3	−7 .0	+0 .6	−2 .4	−4 .1	−3 .2	−3 .9	+2 .4	−1 .2
Middle Pacific Coast	−5 .4	+3 .7	−13 .8	−7 .2	−9 .5	+3 .1	−3 .5	−4 .3	−3 .9	−0 .1	−0 .9	−2 .2
South Pacific Coast	−4 .5	−9 .5	−4 .4	−11 .8	−11 .3	−8 .5	−2 .4	−7 .2	+1 .8	+0 .1	+0 .6	−5 .7
Mean accum. departures	−0 .53	+0 .24	−12 .45	−1 .76	+3 .80	+2 .33	−4 .43	−3 .09	+6 .37	−1 .45	+3 .14	+4 .00
Solar presentation	S	N	S	N	S	N	S	N	S	N	S	N
Relative size of spots	1 .99	(2 .33)	(2 .65)	2 .94	2 .19	1 .51	1 .29	1 .20	0 .75	0 .96	0 .89	0 .53
Excess[1] N.: S. prom'nces	+0 .016	−0 .324	−0 .925	−0 .443	−0 .952	−0. 302	+0 .204	+0 .151	−0 .008	−0 .433	−0 .214	−0 .398
Excess N.; S. faculæ	−0 .099	−0 .156	−0 .464	−0 .211	−0 .228	−0 .588	−0 .273	+0 .079	−0 .672	−1 .727	−0 .460	−0 .304
Excess N.: S. spots	−0 .028	−0 .230	−0 .298	−0 .438	−0 .421	−0 .270	−0 .066	+0 .163	−0 .568	−1 .950	−0 .787	−0 .302
Mean excess N.: S.	−0 .037	−0 .237	−0 .562	−0 .364	−0 .534	−0 .387	−0 .045	+0 .131	−0 .416	−1 .237	−0 .487	−0 .335

[1] Computed by the formulæ $\frac{N-S}{S}$ for north excess, $\frac{N-S}{N}$ for south excess, from quarterly means.

Sun-spots	Port Darwin Lat. 12° 28′ S. Solar Max.		Port Darwin Lat. 12° 28′ S. Solar Min.		Alice Springs Lat. 23° 38′ S. Solar Max.		Alice Springs Lat. 23° 38′ S. Solar Min.		Cape Borda Lat. 35° 45′ S. Solar Max.		Cape Borda Lat. 35° 45′ S. Solar Min.		C. Northumberland Lat. 38° 5′ S. Solar Max.		C. Northumberland Lat. 38° 5′ S. Solar Min.	
Extreme monthly temperature	Max. 1883	Min. 1883	Max. 1888	Min. 1888	Max. 1883	Min. 1883	Max. 1888	Min. 1888	Max. 1883	Min. 1883	Max. 1888	Min. 1888	Max. 1883	Min. 1883	Max. 1888	Min. 1888
January	98°.0	71°.0	93°.8	72°.2	116°.0	54°.0	113°.5	61°.5	91°.0	47°.5	90°.0	48°.5	97°.0	50°.0	95°.0	46°.7
February	97 .0	71 .0	97 .4	71 .8	112 .0	58 .0	109 .0	56 .0	85 .7	48 .5	81 .5	50 .0	91 .0	52 .0	91 .0	44 .0
March	102 .0	68 .0	98 .0	73 .4	98 .0	45 .0	101 .8	49 .0	84 .0	46 .0	80 .0	48 .0	93 .0	44 .0	94 .0	48 .0
April	104 .0	70 .0	98 .0	73 .5	98 .0	40 .0	102 .0	46 .0	78 .0	49 .0	78 .9	44 .8	79 .0	46 .0	88 .0	42 .2
May	100 .0	63 .0	95 .3	69 .0	86 .0	33 .0	86 .0	33 .0	67 .0	43 .0	72 .4	45 .0	67 .0	38 .0	78 .0	39 .0
June	98 .0	66 .0	93 .0	65 .0	87 .0	32 .0	83 .5	28 .0	61 .0	51 .5	61 .9	41 .3	60 .0	42 .0	64 .9	40 .2
July	95 .0	63 .0	98 .0	62 .9	86 .0	26 .0	76 .0	24 .5	61 .0	41 .0	60 .9	39 .7	58 .0	36 .0	65 .4	38 .0
August	95 .0	65 .0	94 .3	64 .5	96 .0	29 .0	90 .5	31 .0	60 .0	44 .7	63 .9	36 .7	62 .0	37 .0	65 .5	34 .0
September	101 .0	63 .0	98 .8	69 .7	97 .0	32 .0	97 .2	31 .0	67 .5	43 .0	76 .7	39 .7	67 .0	41 .0	80 .6	42 .2
October	102 .0	72 .0	100 .0	71 .2	104 .0	44 .0	106 .4	45 .5	69 .0	44 .5	76 .1	43 .3	79 .0	41 .0	78 .7	38 .3
November	102 .0	70 .0	99 .2	72 .1	106 .0	49 .0	110 .9	57 .4	78 .0	45 .0	94 .7	46 .1	84 .0	45 .0	98 .7	46 .2
December	102 .0	70 .0	97 .2	73 .7	116 .0	54 .0	109 .8	65 .8	82 .0	49 .0	92 .8	48 .2	91 .0	44 .0	95 .7	45 .0
Year	104 .0	63 .0	100 .0	62 .9	116 .0	26 .0	113 .5	24 .5	91 .0	41 .0	94 .7	36 .7	97 .0	36 .0	98 .7	34 .0

The classical paper by Mr. C. A. Schott on "Atmospheric Temperature in the United States"[1] gives an instance of a very marked and wide-spread negative mean annual temperature departure of from two to three degrees Fahrenheit, coinciding with the Sun-spot maximum of 1837 to 1838; but there are other instances showing disagreement between the several stations, or an opposite influence on temperature at the Sun-spot maxima. To eliminate the causes of such disagreement in values tabulated from observations in temperate latitudes, it may be necessary to know:

1. The relative activity of the northern and southern solar hemispheres.

2. The temperature departure along a terrestrial latitude parallel, or at least at points differing in longitude by about 180°, in order to allow for any eccentricity in the pole of cold.

Better still would it be to gather the thermal data of the tropical oceans.

To illustrate the results which may be anticipated from a comparison of tropical and temperate temperatures, a table[2] of monthly extreme maximum and minimum temperatures in Australia is given herewith.

Not only for the years, but also largely for the separate months, the maximum temperatures are higher for a time of many Sun-spots in the torrid zone, and lower in the temperate zone. But no single example which could be chosen, would be entirely free from objection; and in citing these comparisons, my object is mainly to direct attention to the desirability of the accumulation and tabulation of special kinds of meteorological data as a means of solving the question of solar variability.

[1] *Smithsonian Contributions to Knowledge*, **21**, Washington, 1876. Curves of secular change, opposite p. 310.

[2] Taken from *Meteorological Observations made at the Adelaide Observatory and other places*, under the direction of Charles Todd, F. R. A. S.

ARC-SPECTRUM OF VANADIUM.

HENRY A. ROWLAND and CALEB N. HARRISON.

THIS paper is a preliminary notice of a series of investigations which we have undertaken on the arc-spectra of certain metals that have hitherto not been carefully studied by modern methods.

The work will be confined to the visible and ultra-violet part of the spectrum. The plates used were in large part selected from a series of plates made some years ago by one of us in the study of the solar spectrum. Others have, however, been taken recently for the purpose of this investigation. They are nineteen inches in length. The grating used was a six-inch Rowland concave of twenty-one and a half feet focal length and ruled with 20,000 lines to the inch. It has the usual mounting, described by Professor Ames in the *Johns Hopkins University Circular* of May 1889.

The arc-spectra and solar spectrum are on each plate and permit comparison according to the method of Rowland.

In order to eliminate all lines due to impurities in the study of an element, a comparison is made with the spectra of the carbon poles and of all elements likely to be associated with the element. This is accomplished by the superposition of plates which are on the scale, thus insuring coincidence of corresponding lines. The intensity of these lines are an element in their determination.

The measuring engine employed has a nearly perfect screw and a pitch so as to measure wave-lengths directly in ten-millionths of a millimeter.

The basis of all measurements is the Table of Standard Wave-Lengths.[1]

A correction for each line is obtained by measuring numerous solar standard lines in addition to those of the element studied. The difference in wave-lengths taken from the table and the corresponding lines measured give when platted a correction curve for each plate. The character of line and its posi-

[1] ROWLAND, *A New Table of Standard Wave-lengths. Astron. and A. P.*, **12**, 1893.

tion on the plate is considered in assigning weights preparatory to drawing the correction curves. The wave-length of each line is the mean of at least two readings, direct and reversed. By "direct" reading is meant that which is obtained when the plate is being moved so that the successive lines coming in the field of the microscope are of increasing wave-length, and by "reversed" reading that obtained when the plate is moving so that successive lines seen through the microscope are of decreasing wave-length.

In the following tables the intensities are given on a scale from 1, n (very faint and nebulous on the plate) to 15 (strongest line). The column headed wave-length (uncorrected) are readings taken from the engine. Corrections marked 1 and 2 are obtained respectively from the correction curve and values calculated for the Earth's motion for latitude 39° 18′. The symbol * after a corrected wave-length means the average of several measurements on different plates.

Hesselberg's readings are taken from his article in this JOURNAL, "Note on the Chemical Composition of the Mineral Rutile," Vol. VI., p. 22, June 1897.

The wave-lengths from 4200.000 to 5786.000, inclusive, were measured from plates recently taken, and their time of exposure was duly recorded. This permitted us to make the correction for the Earth's motion. We were unable to apply a similar correction to other wave-lengths on account of not having a record of their date of exposure.

In measuring the lines in the arc-spectra numerous standard solar lines were also measured for the purpose of drawing a correction curve. The plates marked "Solar Lines for Standards" have in the first column micrometer readings; the second column, headed "Standard," are taken from the Table of Standard Wave-lengths; the third column, marked "Difference," is the difference between the standard and the micrometer reading, with the proper sign annexed. The remaining columns are values calculated as due to the Earth's motion. The symbols, †, ‡, *, ‖, represent the relative weights assigned to standards, and are in ascending scale of magnitude.

SOLAR LINES FOR STANDARDS.

PLATE 32

Micrometer readings	Standard	Difference	Micrometer readings	Standard	Difference
3079.715	.724‖	—.009	3232.414	.404‖	+.010
3080.850	.863‡	—.013	3246.133	.124‡	+.009
3086.879	.891‡	—.012	3247.694	.680†	+.014
3094.723	.739‖	—.016	3260.389	.384*	+.005
3094.999	95.003‖	—.004	3267.846	.839‖	+.007
3115.141	.160‖	—.019	3274.093	.092†	+.001
3121.265	.275‡	—.010	3287.792	.791‡	+.001
3137.443	.441‖	+.002	3295.955	.957‖	—.002
3140.868	.869‖	—.001	3302.510	.501‡	+.009
3167.299	.290*	+.009	3303.648	.648‡	.000
3172.179	.175‡	+.004	3308.928	.928*	.000
3176.117	.104*	+.013	3318.162	.163*	—.001
3188.140	.164‡	—.024	3331.748	.741*	+.007
3200.030	.032‡	—.002	3348.015	.011*	+.004
3218.400	.390‖	+.010	3351.888	.877‖	+.011
3224.378	.368‖	+.010	3356.230	.222‖	+.008
3231.450	.421†	+.029	3377.669	.667‡	+.002

PLATE 36.

Micrometer readings	Standard	Difference	Micrometer readings	Standard	Difference
3405.200	.272‡	—.072	3558.670	.670†	.000
3406.510	.581‖	—.071	3564.686	.680‡	+.006
3406.886	.955‖	—.069	3570.236	.225†	+.011
3425.672	.721‖	—.049	3581.337	.344†	—.007
3440.720	.759†	—.039	3583.490	.483‖	+.007
3441.095	.135†	—.040	3597.198	.192‖	+.006
3455.338	.384‖	—.046	3600.875	.880‡	—.005
3464.571	.609‖	—.038	3612.234	.217‖	+.017
3486.010	.036‡	—.036	3618.946	.924†	+.022
3491.446	.464‖	—.018	3622.170	.147‡	+.023
3497.990	.991‡	—.001	3623.345	.332‖	+.013
3500.698	.721‖	—.023	3631.632	.619†	+.013
3510.987	.987‖	.000	3640.555	.536‡	+.019
3518.471	.487	—.016	3652.614	.692‖	+.022
3521.392	.404†	—.012	3658.719	.688‖	+.031
3540.257	.266‡	—.009	3667.424	.397‖	+.027
3545.339	.333*	+.006	3680.077	.064†	+.013
3550.000	.006‖	—.006	3683.228	.202‡	+.026

PLATE 36—*continued.*

Micrometer readings	Standard	Difference	Micrometer readings	Standard	Difference
3687.630	.607†	+.023	3770.156	.130*	+.026
3695.220	.194‡	+.026	3780.870	.846‖	+.024
3707.223	.186‡	+.037	3781.347	.330‖	+.017
3709.385	.397†	—.012	3783.700	.674‡	+.026
3716.595	.585‡	+.010	3794.039	.014‖	+.025
3720.105	.086†	+.019	3795.176	.150†	+.026
3732.566	.542‡	+.024	3804.198	.153‖	+.045
3737.308	.282†	+.026	3805.521	.487*	+.024
3743.529	.502†	+.027	3820.590	.567†	+.023
3745.718	.701‡	+.017	3821.348	.318‡	+.030
3756.240	.211‖	+.029	3823.679	.651‡	+.028
3763.968	.942†	+.026	3826.039	.024†	+.015

PLATE 40.

Micrometer readings	Standard	Difference	Micrometer readings	Standard	Difference
3804.105	.153‖	—.048	3961.682	.676†	+.006
3805.441	.487*	—.046	3971.482	.478‖	+.004
3815.940	.985†	—.045	3977.898	.891‖	+.007
3821.278	.318†	—.040	3981.927	.914‖	+.013
3823.617	.651‡	—.034	3984.086	.078†	+.008
3826.007	.024†	—.017	3987.243	.216†	+.017
3832.418	.446†	—.028	4003.927	.916*	+.011
3836.192	.226‖	—.034	4016.584	.578‖	+.006
3856.509	.517‡	—.008	4029.805	.796‖	+.009
3860.032	.048†	—.016	4030.918	.914†	+.004
3864.425	.441‖	—.016	4033.221	.225†	—.004
3871.519	.528*	—.009	4045.970	.975†	—.005
3875.203	.224‖	—.021	4048.895	.893‡	+.002
3886.423	.427†	—.004	4055.708	.701‖	+.007
3897.588	.599‖	—.011	4062.599	.602‖	—.003
3905.662	.666†	—.004	4071.920	.904†	+.016
3916.877	.875‖	+.002	4073.928	.920‖	+.008
3924.680	.669‖	+.021	4077.879	.883†	—.004
3925.355	.345‖	+.010	4083.765	.767‡	—.002
3925.796	.792‖	+.004	4088.712	.716‖	—.004
3937.487	.474‖	+.013	4103.100	.101‡	—.001
3944.160	.159†	+.001	4107.651	.646‡	+.005
3950.109	.101‖	+.008	4114.612	.600‖	+.012
3950.498	.497‖	+.001	4121.967	.968‖	—.001
3954.012	.001‖	+.011	4157.938	.948‖	—.010
3957.189	.180†	+.009	4185.055	.063‖	—.008
3960.439	.429‖	+.010	4197.254	.251‡	+.003

PLATE 44[1] (JAN. 24, 12:11 P. M.).

Micrometer readings	Standard	Difference	Correction 2	Micrometer readings	Standard	Difference	Correction 2
4185.098	.063	+.035	+.003	4260.683	.638‡	+.045	+.003
4199.311	.263*	+.048	+.003	4267.980	.958‡	+.022	+.003
4202.241	.188*	+.053	+.003	4271.967	.924†	+.033	+.003
4215.714	.687*	+.027	+.003	4283.209	.170*	+.039	+.003
4222.415	.381*	+.034	+.003	4289.568	.523*	+.045	+.003
4226.932	.892†	+.040	+.003	4289.929	.881*	+.038	+.003
4250.998	.956‡	+.042	+.003	4293.293	.249*	+.044	+.003
4254.540	.502‡	+.038	+.003				

NEW PLATE 44.

Micrometer readings	Standard	Difference	Correction 2	Micrometer readings	Standard	Difference	Correction 2
4274.994	.958*	+.036	+.003	4462.594	.621♯	—.027	+.003
4289.553	.523	+.030	+.003	4468.635	.663♯	—.028	+.003
4293.268	.249‡	+.019	+.003	4489.871	.911♯	—.040	+.003
4299.170	.152*	+.018	+.003	4494.700	.735*	—.035	+.003
4306.097	.071‡	+.026	+.003	4501.404	.444*	—.040	+.003
4318.840	.818	+.022	+.003	4508.412	.456*	—.044	+.003
4325.957	.940‡	+.017	+.003	4517.656	.702♯	—.046	+.003
4343.409	.387*	+.022	+.003	4533.357	.419♯	—.062	+.003
4369.958	.943*	+.015	+.003	4541.630	.690♯	—.060	+.003
4376.119	.103*	+.016	+.003	4544.780	.864♯	—.084	+.003
4383.725	.721†	+.004	+.003	4546.065	.129♯	—.064	+.003
4404.925	.927‡	—.002	+.003	4549.735	.808♯	—.073	+.003
4407.840	.850‡	—.010	+.003	4563.854	.939*	—.085	+.003
4415.291	.299‡	—.008	+.003	4571.186	.277*	—.091	+.003
4425.598	.609*	—.011	+.003	4578.639	.731	—.092	+.003
4435.099	.132†	—.033	+.003	4590.029	.129	—.100	+.003
4454.925	.950‡	—.025	+.003	4603.023	03.126♯	—.103	+.003
4460.439	.462♯	—.023	+.003				

PLATE 48 (JANUARY 24, 12:37 P.M.).

Micrometer readings	Standard	Difference	Correction 2	Micrometer readings	Standard	Difference	Correction 2
4602.231	.183	+.048	+.004	4643.640	.645†	—.005	+.004
4607.559	.509‡	+.050	+.004	4648.880	.835†	+.045	+.004
4611.500	.453†	+.047	+.004	4668.344	.303‡	+.041	+.004
4637.732	.683	+.049	+.004	4678.394	.353‡	+.041	+.004
4638.238	.194	+.044	+.004	4679.071	.028‡	+.043	+.004

[1] The symbol ♯ indicates solar wave-length, not standard.

PLATE 48 (JANUARY 24, 12:37 P.M.).—*Continued.*

Micrometer readings	Standard	Difference	Correction 2	Micrometer readings	Standard	Difference	Correction 2
4683.785	.743‖	+.042	+.004	4823.700	.697*	+.003	+.004
4686.440	.395‖	+.045	+.004	4859.924	.934*	—.010	+.004
4690.360	.324‖	+.036	+.004	4903.470	.488†	—.018	+.004
4691.610	.581†	+.029	+.004	4919.147	.183‡	—.036	+.004
4703.218	.180‡	+.038	+.004	4920.665	.682†	—.017	+.004
4714.630	.599†	+.031	+.004	4934.215	.247‡	—.032	+.004
4722.370	.349‡	+.021	+.004	4957.763	.786†	—.023	+.004
4727.654	.628‡	+.021	+.004	4973.244	.274‖	—.030	+.004
4754.245	.226‡	+.019	+.004	4978.722	.782†	—.060	+.004
4783.618	.601†	+.017	+.004	4981.866	.915‖	—.049	+.004
4805.275	.253‡	+.022	+.004	4994.260	.316‖	—.059	+.004
4810.725	.723†	+.002	+.004	4999.628	.693*	—.065	+.004

PLATE 51 (JAN. 24, 10:8 P. M.).

Micrometer readings	Standard	Difference	Correction 2	Micrometer readings	Standard	Difference	Correction 2
4903.479	.488‡	—.009	+.005	5127.592	.530*	+.062	+.005
4920.697	.682‡	+.015	.005	5133.870	.871‡	—.001	+.005
4924.111	.109*	+.002	.005	5139.642	.645†	—.003	+.005
4934.240	.247†	—.007	.005	5141.910	.916‖	—.006	+.005
4957.479	.482†	—.003	.005	5146.658	.664‖	—.006	+.005
4957.793	.786†	+.007	.005	5151.055	.026†	+.029	+.005
4973.287	.274‖	+.013	.005	5155.938	.937‖	+.001	+.005
4978.774	.782‡	—.008	.005	5159.230	.240‖	—.010	+.005
4980.348	.362‡	—.014	.005	5162.452	.448‖	+.004	+.005
4981.915	.915‖	.000	.005	5165.581	.588‖	—.007	+.005
4994.320	.316‖	+.004	.005	5171.770	.783*	—.013	+.005
4999.686	.693‡	—.007	.005	5172.855	.871†	—.016	+.005
5005.896	.904‖	—.008	.005	5173.912	.912‖	.000	+.005
5007.425	.431‡	—.006	.005	5193.128	.139‖	—.011	+.005
5014.424	.422‡	+.002	+.005	5204.697	.708‡	—.011	+.005
5020.210	.210*	.000	+.005	5202.464	.483‡	—.019	+.005
5050.009	.008‖	+.001	+.005	5210.543	.556*	—.013	+.005
5060.254	.252*	+.002	+.005	5215.335	.352*	—.017	+.005
5064.836	.833‖	+.003	+.005	5217.541	.559‖	—.018	+.005
5068.950	.946‖	+.004	+.005	5225.669	.690‖	—.021	+.005
5083.519	.525‖	—.006	+.005	5233.095	.124‡	—.029	+.005
5090.956	.959‖	—.003	+.005	5242.632	.662*	—.030	+.005
5097.183	.176*	+.007	+.005	5250.787	.825‖	—.038	+.005
5105.718	.719‖	—.001	+.005	5253.600	.649‖	—.049	+.005
5110.585	.570‡	+.015	+.005	5273.286	.344‡	—.058	+.005
5115.574	.558‖	+.016	+.005	5281.909	.968*	—.059	+.005
5121.804	.797‡	+.007	+.005	5288.640	.708‖	—.068	+.005

PLATE 54 (JANUARY 18, 1 : 02 P.M.).

Micrometer readings	Standard	Difference	Correction 2	Micrometer readings	Standard	Difference	Correction 2
5154.295	.237‖	+.058	+.005	5288.742	.708*	+.034	+.005
5159.280	.240‖	+.040	+.005	5296.956	.873*	+.081	+.005
5262.496	.448‖	+.048	+.005	5307.586	.546*	+.040	+.005
5165.625	.588‖	+.037	+.005	5316.835	.870†	—.035	+.005
5171.834	.783*	+.051	+.005	5324.404	.373†	+.031	+.005
5173.983	.912‖	+.071	+.005	5333.111	.092*	+.019	+.005
5183.824	.792†	+.032	+.005	5349.680	.623†	+.057	+.005
5188.900	.948‡	+.048	+.005	5353.586	.592*	—.006	+.005
5189.075	.020‡	+.055	+.005	5370.176	.165*	+.011	+.005
5193.189	.139‡	+.050	+.005	5393.385	.378*	+.007	+.005
5198.938	.885*	+.053	+.005	5397.344	.346‖	—.002	+.005
5202.523	.483‡	+.040	+.005	5405.989	.987‖	+.002	+.005
5210.611	.556‖	+.055	+.005	5415.418	.421*	—.003	+.005
5215.401	.352‡	+.049	+.005	5424.276	.284†	—.008	+.005
5217.608	.559*	+.049	+.005	5434.724	.742†	—.018	+.005
5225.752	.690*	+.062	+.005	5447.112	.130‡	—.018	+.005
5230.075	.014*	+.061	+.005	5455.818	.826†	—.008	+.005
5233.163	.124‡	+.039	+.005	5462.683	.732*	—.049	+.005
5242.710	.662*	+.048	+.005	5463.147	.174*	—.027	+.005
5250.435	.391‖	+.044	+.005	5466.585	.608*	—.023	+.005
5253.690	.649‖	+.041	+.005	5528.575	.636‡	—.061	+.005
5264.409	.371†	+.038	+.005	5534.995	5535.073*	—.078	+.005
5265.941	.884†	+.057	+.005	5543.344	.418‖	—.074	+.005
5270.536	.495‡	+.041	+.005	5544.092	.158*	—.066	+.005
5273.600	.554‡	+.046	+.005	5555.030	.113‖	—.083	+.005
5283.844	.803‡	+.041	+.005				

PLATE 58 (JANUARY 18, 2:07 P.M.).

Micrometer readings	Standard	Difference	Correction 2	Micrometer readings	Standard	Difference	Correction 2
5555.130	.113‖	+.017	+.007	5658.102	.096*	+.006	+.007
5569.858	.848‡	+.010	+.007	5662.750	.745‡	+.005	+.007
5576.326	.319‖	+.007	.007	5679.264	.249‖	+.016	+.007
5582.205	.195*	+.010	+.007	5682.880	.861*	+.019	+.007
5588.990	.980‡	+.010	+.007	5688.445	.434‡	+.011	+.007
5598.731	.715‡	+.016	+.007	5708.635	.620‡	+.015	+.007
5601.512	.501‡	+.011	+.007	5709.609	.616†	—.007	+.007
5615.530	.526‖	+.004	+.007	5711.323	.318‡	+.005	+.007
5615.882	.879‡	+.003	+.007	5715.325	.309‡	+.016	+.007
5624.263	.253‖	+.010	+.007	5742.076	.066*	+.010	+.007
5624.778	.768*	+.010	+.007	5753.354	.342‡	+.012	+.007
5634.182	.169‡	+.015	+.007	5763.220	.215‡	+.005	+.007

PLATE 58—*continued.* (JANUARY 18, 2:07 P.M.)

Micrometer readings	Standard	Difference	Correction 2	Micrometer readings	Standard	Difference	Correction 2
5782.350	.346‡	+.004	+.007	5805.445	.448‡	—.003	+.007
5788.142	.136‡	+.006	+.007	5806.950	.954‡	—.004	+.007
5791.207	.207†	.000	+.007	5809.440	.437‡	+.003	+.007
5798.080	.087*	—.007	+.007	5816.602	.594‡	+.008	+.007
5798.403	.400‡	+.003	+.007				

THE ARC-SPECTRUM OF VANADIUM.

Wave-length (uncorrected)	Correction[1]	Correction	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
3094.779	+.014		1, n	3094.793	
3101.024	+.014		1	3101.038	
3102.401	+.014		10	3102.415	
3109.269	+.014		1	3109.283	
3109.367	+.014		1	3109.381	
3110.812	+.014		1	3110.826	
3113.024	+.014		1	3113.038	
3118.482	+.014		8	3118.496	
3120.836	+.013		1	3120.849	
3121.248	+.013		1	3121.261	
3123.008	+.012		1	3123.020	
3125.390	+.012		5	3125.402	
3126.327	+.011		5	3126.338	
3130.398	+.010		5	3130.408	
3133.446	+.009		5	3133.455	
3135.052	+.008		1	3135.060	
3137.298	+.007		1	3137.305	
3139.856	+.006		1	3139.862	
3142.591	+.005		2	3142.596	
3146.084	—.002		1	3146.086	
3164.950	—.005		1	3164.945	
3168.250	—.006		1	3168.244	
3183.534	—.009		9	3183.525	
3184.106	—.009		10	3184.097	
3185.516	—.009		10	3185.507	
3187.830	—.010		4	3187.820	
3188.634	—.010		2	3188.624	
3190.808	—.010		5	3190.798	
3194.040	—.010		1	3194.030	
3198.131	—.010		1	3198.121	
3199.944	—.010		1	3199.934	
3202.505	—.010		6	3202.495	
3205.388	—.010		1	3205.378	
3205.699	—.010		3	3205.689	
3207.531	—.010		4	3207.521	
3208.474	—.010		1	3208.464	
3210.263	—.010		1	3210.253	
3210.556	—.010		1	3210.546	
3212.560	—.010		1	3212.550	
3215.497	—.010		1	3215.487	
3217.250	—.010		1	3217.240	
3218.995	—.010		1	3218.985	
3226.233	—.010		1	3226.223	

[1] Obtained from correction curve.

VANADIUM—*continued,*

Wave-length (uncorrected)	Correction 1	Correction	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
3227.530	—.010		1	3227.520	
3229.734	—.010		1	3229.724	
3230.775	—.010		1	3230.765	
3232.074	—.010		1	3232.064	
3233.310	—.010		2	3233.300	
3233.888	—.010		1	3233.878	
3238.000	—.010		2	3237.990	
3249.700	—.010		1	3249.690	
3250.904	—.010		1	3250.894	
3251.995	—.009		1	3251.886	
3254.845	—.009		2	3254.836	
3255.778	—.009		1	3255.769	
3256.900	—.008		1	3256.892	
3259.665	—.007		1	3259.658	
3261.205	—.007		1	3261.198	
3262.429	—.007		1	3262.422	
3262.187	—.007		1	3262.180	
3266.033	—.006		1	3266.027	
3267.828	—.005		8	3267.823	
3271.247	—.004		8	3271.243	
3271.763	—.004		2	3271.759	
3273.141	—.004		1	3273.137	
3276.255	—.003		8	3276.252	
3277.884	—.003		1, n	3277.881	
3278.055	—.002		1, n	3278.053	
3279.978	—.002		1	3279.976	
3281.240	—.002		1	3281.238	
3282.661	—.002		1	3282.659	
3284.492	—.002		1	3284.489	
3285.134	—.001		1	3285.133	
3288.560	—.001		1	3288.559	
3288.438	—.001		1	3288.437	
3289.516	—.001		2	3289.515	
3290.363	—.001		2	3290.362	
3291.806	—.001		3	3291.805	
3298.277	—.001		1	3298.276	
3299.224	—.001		2	3299.223	
3309.306	—.001		2	3309.305	
3313.142	—.001		1	3313.141	
3314.144	—.001		1	3314.143	
3314.980	.000		1	3314.980	
3322.085	—.001		1	3322.084	
3324.515	—.001		1	3324.514	
3329.985	—.002		3	3329.983	
3333.695	—.002		1	3333.693	
3356.480	—.009		2	3356.471	
3365.683	—.013		3	3365.670	
3405.936	+.076		1, n	3406.012	
3406.914	+.075		1, n	3406.989	
3414.300	+.070		1, n	3414.370	

VANADIUM—*continued.*

Wave-length (uncorrected)	Correction 1	Correction	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
3418.608	+.068		1, n	3418.676	
3425.145	+.059		1, n	3425.204	
3457.010	+.038		1, n	3457.048	
3489.625	+.023		1, n	3489.648	
3497.062	+.019		1, n	3497.081	
3501.597	+.017		1	3501.614	
3517.425	+.011		1	3517.436	
3529.870	+.006		1	3529.876	
3533.816	+.004		1	3533.820	
3543.629	+.002		1	3543.631	
3545.329	+.001		1, n	3545.330	
3545.418	+.001		1	3545.419	
3551.670	−.001		1, n	3551.669	
3553.413	−.001		1	3553.412	
3573.659	−.007		1	3573.652	
3574.922	−.007		1	3574.915	
3578.015	−.008		1	3578.007	
3582.962	−.009		1	3582.953	
3583.854	−.010		1	3583.840	
3589.900	−.011		1	3589.889	
3592.170	−.011		1	3592.159	
3593.530	−.011		1	3593.519	
3600.179	−.013		1	3600.166	
3639.180	−.020		1	3639.160	
3639.740	−.020		1	3639.720	
3644.013	−.021		1	3644.023	
3644.859	−.021		1	3644.038	
3649.078	−.021		1	3649.057	
3663.716	−.022		1, n	3663.694	
3665.278	−.022		1, n	3665.256	
3667.863	−.022		1, n	3667.841	
3671.363	−.023		1	3671.840	
3672.542	−.023		1, n	3672.519	
3675.858	−.023		2	3675.835	
3676.830	−.023		1, n	3676.807	
3680.078	−.023		1, n	3680.055	
3680.237	−.023		1	3680.214	
3683.266	−.023		3	3683.243	
3683.626	−.023		1	3683.603	
3686.415	−.023		3	3686.392	
3688.230	−.023		3	3688.207	
3690.431	−.023		3	3690.407	
3692.380	−.023		3	3692.357	
3695.472	−.023		1, n	3695.449	
3696.018	−.023		4	3695.995	
3704.687	−.023		1	3704.664	
3704.854	−.023		7	3704.831	
3705.190	−.023		5	3705.167	
3706.190	−.023			3706.167	
3708.875	−.023		1	3708.852	

VANADIUM — *continued.*

Wave-length (uncorrected)	Correction 1	Correction	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
3719.074	—.023		1	3719.051	
3719.147	—.023		1	3719.124	
3722.159	—.023		1	3722.136	
3722.357	—.023		1	3722.334	
3738.158	—.023		1	3738.129	
3738.923	—.023		1	3738.901*	
3740.397	—.023		1	3740.374*	
3741.653	—.023		1	3741.630	
3778.835	—.027		3	3778.808	
3790.475	—.027		2	3790.448	
3790.620	—.027		1	3790.593	
3800.019	—.027		3	3799.992	
3803.640	—.027		3	3803.613	
3807.378	+.047		2	3807.425	
3807.579	+.047		3	3807.626	
3808.090	+.046		4	3808.136	
3813.567	+.045		4	3813.612	
3818.327	+.043		5	3818.370	
3820.044	+.043		4	3820.087	
3820.616	—.027		2	3820.589	
3821.566	+.042		4	3821.607	
3823.035	—.027		2	3823.008*	
3828.640	+.040		7	3828.680	
3840.833	+.033		6	3840.866	
3844.533	+.032		4	3844.565	
3847.423	+.030		3	3847.453	
3849.404	+.029		2	3849.433	
3855.460	+.026		4	3855.486	
3855.939	+.026		7	3855.965	
3864.959	+.021		5	3864.980	
3875.179	+.016		5	3875.195	
3886.681	+.010		2	3886.691	
3890.290	+.008		4	3890.298	
3892.465	+.006		4	3892.471	
3896.254	+.005		2	3896.259	
3898.079	+.003		1	3898.082	
3902.369	+.002		7	3902.371	
3909.997	—.002		5	3909.995	
3914.441	—.004		1	3914.437	
3919.605	—.005		1	3919.600	
3922.029	—.006		1	3922.023	
3922.554	—.006		3	3922.548	
3924.775	—.007		3	3924.768	
3925.357	—.007		3	3925.350	
3933.784	—.009		3	3933.775	
3944.143	—.010		3	3944.133	
3952.083	—.010		1	3952.073	
3961.662	—.010		5	3961.652	
3968.597	—.009		1	3968.588	
3979.549	—.009		1	3979.540	

***Average of four or more measurements.**

VANADIUM—*continued.*

Wave-length (uncorrected)	Correction [1]	Correction 2	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
3990.702	—.009		5	3990.693	
3992.925	—.009		3	3992.916	
3998.856	—.009		3	3998.847	
4005.847	—.009		1, n	4005.838	
4022.046	—.008		1, n	4022.038	
4023.516	—.008		1, n	4023.508	
4031.968	—.007		1	4031.961	
4033.199	—.007		3	4033.192	
4034.626	—.007		2	4034.619	
4042.765	—.006		1	4042.759	
4051.490	—.005		4	4051.485	
4057.211	—.005		2	4057.206	
4057.961	—.005		1	4057.956	
4064.065	—.005		2	4064.061	
4071.668	—.004		2	4071.664	
4077.853	—.004		1, n	4077.849	
4090.707	—.004		5	4090.703	
4092.536	—.004		2	4092.532	
4095.611	—.004		5	4095.607	
4098.514	—.004		1, n	4098.510	
4099.925	—.004		7	4199.921	
4102.289	—.004		3	4102.285	
4104.520	—.004		2	4104.516	
4107.603	—.004		1	4107.599	
4109.910	—.004		7	4109.906	
4111.920	—.004		5, R	4111.916	
4113.641	—.004		3	4113.637	
4115.316	—.005		7	4115.311	
4116.636	—.005		9	4116.631	
4118.325	—.005		1, n	4118.320	
4119.580	—.005		3	4119.575	
4120.660	—.005		2	4120.655	
4124.200	—.004		1	4124.196	
4128.156	—.004		7	4128.152	
4131.301	—.004		1, n	4131.297	
4132.127	—.004		6	4132.123	
4134.620	—.003		7	4134.617	
4159.819	+.003		2	4159.822	
4174.145	+.010		1	4174.155	
4182.769	—.042	+.003	1	4182.733	
4183.110	—.042	+.003	4	4183.071*	
4189.988	+.020	+.003	2	4190.011	
4202.545	—.042	+,003	2	4202.506	
4205.240	—.042	+.003	2	4205.201	
4210.041	—.042	+.003	5	4210.002	
4225.408	—.042	+.003	1	4225.369	
4226.910	—.042	+.003	4, R	4226.871	
4232.643	—.042	+.003	7	4232.604	
4233.146	—.042	+.003	7	4233.007	
4234.188	—.042	+.003	7	4234.149	

[1] Due to Earth's motion. * Average of four or more measurements.

VANADIUM — *continued.*

Wave-length (uncorrected)	Correction 1	Correction 2	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
4234.710	—.042	+.003	7	4234.671	
4235.948	—.042	+.003	4	4235.909	
4257.556	—.042	+.003	4	4257.517	
4259.493	—.042	+.003	4	4259.454	
4262.350	—.042	+.003	4	4262.311	
4268.826	—.042	+.003	0	4268.787	
4271.745	—.042	+.003	17	4271.706	4268.85
4277.140	—.042	+.003	7	4277.101	4271.80
4284.247	—.042	+.003	5	4284.208	
4291.997	—.022	+.003	1	4291.978	
4296.285	—.022	+.003	7	4296.266	
4297.859	—.022	+.003	7	4297.840	
4299.259	—.022	+.003	1	4299.240	
4303.716	—.022	+.003	2	4303.697	
4309.968	—.022	+.003	7	4309.949	
4318.822	—.022	+.003	2	4318.803	
4330.209	—.021	+.003	0	4330.181	
4333.003	—.021	+.003	10	4332.985	4330.15
4341.178	—.019	+.003	10	4341.162	4333.00
4353.054	—.017	+.003	18	4353.040	4341.15
4355.151	—.016	+.003	4	4355.138	4353.05
4356.117	—.016	+.003	4	4356.104	
4363.700	—.013	+.003	4	4363.690	
4364.387	—.013	+.003	4	4364.377	
4368.765	—.012	+.003	4	4368.756	
4373.390	—.010	+.003	6	4373.383	
4373.991	—.010	+.003	3	4373.984	
4379.389	.000	+.003	1	4379.392	
4380.715	—.007	+.003	4	4380.719	4379.42
4381.191	—.007	+.003	1	4381.187	
4384.877	—.005	+.003	1	4384.875	4384.95
4390.142	—.003	+.003	7, R	4390.142	4390.15
4392.233	—.002	+.003	4	4392.234	
4393.256	—.001	+.003	3	4393.258	
4393.998	—.001	+.003	4	4394.000	
4395.379	.000	+.003	10, R	4395.382	4395.40
4397.389	.000	+.003	1	4397.392	
4400.733	+.002	+.003	10	4400.738	4400.75
4403.825	+.003	+.093	4	4403.831	
4406.271	+.003	+.003	8	4406.277	
4406.798	+.004	+.003	8, R	4406.805	4406.85
4407.793	+.005	+.003	8, R	4407.801	4407.90
4408.360	+.005	+.003	5, R	4408.368	4408.40
4408.657	+.005	+.003	5, R	4408.665	4408.65
4412.290	+.006	+.003	4	4412.299	
4416.615	+.008	+.003	5	4416.626	4416.65
4421.726	+.010	+.003	10	4421.739	
4423.361	+.011	+.003	8	4423.375	
4424.068	+.011	+.003	2	4424.082	
4424.729	+.011	+.003	4	4424.743	

VANADIUM — *continued.*

Wave-length (uncorrected)	Correction 1	Correction 2	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
4425.579	+.012	+.003	1	4425.594	
4428.660	+.013	+.003	5	4428.676	
4436.290	+.016	+.003	7	4436.309	
4437.985	+.016	+.003	7	4438.004	4438.03
4441.826	+.018	+.003	2	4441.847	4441.90
4443.486	+.019	+.003	4	4443.508	
4444.358	+.019	+.003	3	4444.380	4444.40
4449.718	+.020	+.003	4	4449.741	
4451.046	+.021	+.003	4	4451.070	
4452.156	+.021	+.003	8	4452.180	4452.12
4454.913	+.023	+.003	1	4454.939	
4456.047	+.023	+.003	1	4456.073	
4456.642	+.023	+.003	3	4456.668	
4457.605	+.024	+.003	3	4457.632	
4458.888	+.024	+.003	1, n	4458.915	
4459.891	+.024	+.003	8	4459.918	4459.95
4460.434	+.025	+.003	10, R	4460.462	4460.45
4460.821	+.025	+.003	4	4460.849	
4462.504	+.026	+.003	10	4462.533	4462.55
4465.645	+.027	+.003	3	4465.675	
4468.143	+.028	+.003	3	4468.174	
4468.900	+.028	+.003	3	4468.931	
4469.840	+.028	+.003	7	4469.871	4469.90
4470.950	+.029	+.003	1	4470.872	
4474.174	+.030	+.003	7	4474.207	
4474.866	+.030	+.003	7	4474.899	
4480.170	+.033	+.003	3	4480.206	
4489.056	+.037	+.003	7	4489.096	
4490.940	+.038	+.003	4	4490.981	
4491.298	+.040	+.003	2	4491.343	
4491.607	+.038	+.003	1	4491.648	
4496.190	+.040	+.003	5	4496.233	
4497.531	+.040	+.003	5	4497.574	
4500.955	+.043	+.003	2	4501.001	
4501.366	+.043	+.003	1	4501.412	
4502.075	+.043	+.003	4	4502.121	
4506.696	+.045	+.003	1	4506.744	
4509.413	+.047	+.003	2	4509.463	
4511.554	+.048	+.003	2	4511.605	
4513.740	+.049	+.003	2	4513.792	
4514.305	+.049	+.003	4	4514.357	
4515.676	+.050	+.003	1	4515.729	
4517.683	+.052	+.003	3	4517.738	
4520.275	+.053	+.003	2	4520.331	
4520.629	+.053	+.003	2	4520.685	
4524.320	+.055	+.003	5	4524.378	
4525.279	+.055	+.003	2	4525.337	
4528.108	+.057	+.003	3	4528.168	
4529.415	+.058	+.003	2	4529.476	
4530.910	+.059	+.003	3	4530.972	

VANADIUM—*continued.*

Wave-length (uncorrected)	Correction 1	Correction 2	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
4534.044	+.060	+.003	3	4534.107	
4537.768	+.063	+.003	4	4537.834	
4540.112	+.064	+.003	4	4540.179	
4545.496	+.067	+.003	10	4545.566	4545.62
4549.751	+.070	+.003	8	4549.824	4549.85
4551.941	+.072	+.003	2	4552.016	
4552.660	+.072	+.003	5	4552.735	
4560.813	+.077	+.003	7	4560.893	
4564.673	+.080	+.003	1	4564.756	
4571.870	+.086	+.003	5	4571.959	
4577.255	+.090	+.003	7	4577.348	4577.40
4578.813	+.092	+.003	5	4578.908	
4579.278	+.092	+.003	2	4579.373	
4580.466	+.093	+.003	8	4580.562	4580.55
4581.313	+.093	+.003	1	4581.409	
4583.868	+.096	+.003	2	4583.967	
4586.454	+.097	+.003	8	4586.554	4586.55
4591.303	+.100	+.003	5	4591.406	4594.30
4594.197	+.016	.003	10, R	4594.216	
4606.366	—.049	+.004	4	4606.321	
4607.435	—.049	+.004	1	4607.390	
4608.680	—.049	+.004	1, n	4608.635	
4609.866	—.049	+.004	4	4609.821	
4611.148	—.049	+.004	1	4611.103	
4614.020	—.048	+.004	1, n	4613.976	
4614.138	—.048	+.004	1, n	4614.094	
4616.234	—.048	+.004	11, n	4616.190	
4619.940	—.048	+.004	0	4619.896	
4621.470	—.048	+.004	1, n	4621.426	
4624.625	—.048	+.004	4	4624.581	
4626.710	—.048	+.004	4	4626.666	
4630.280	—.048	+.004	1, n	4630.236	
4635.389	—.047	+.004	7	4635.346	
4636.386	—.047	+.004	1, n	4636.343	
4640.275	—.047	+.004	5	4640.232	
4640.959	—.047	+.004	5	4640.916	
4644.281	—.046	+.004	1	4644.239	
4644.666	—.046	+.004	2	4644.624	
4646.198	—.046	+.004	1	4646.156	
4646.613	—.046	+.004	8	4646.571	
4648.088	—.046	+.004	1, n	4648.046	
4649.110	—.046	+.004	2	4649.068	
4653.147	—.045	+.004	1	4653.106	
4655.451	—.045	+.004	1, n	4655.410	
4657.179	—.045	+.004	1, n	4657.138	
4662.645	—.044	+.004	1, n	4662.605	
4663.354	—.044	+.004	3	4663.314	
4669.527	—.043	+.004	1	4669.487	
4670.705	—.043	+.004	8	4670.666	
4673.874	—.042	+.004	1	4673.836	

VANADIUM—*continued.*

Wave-length (uncorrected)	Correction 1	Correction 2	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
4679.998	—.041	+.004	1	4679.961	
4681.110	—.041	+.004	1	4681.073	
4684.670	—.040	+.004	3	4684.634	
4687.135	—.039	+.004	5	4687.100	
4690.472	—.038	+.004	1, n	4690.438	
4699.537	—.036	+.004	2	4699.505	
4702.720	—.035	+.004	1, n	4702.689	
4705.308	—.035	+.004	3	4705.278	
4706.387	—.034	+.004	5	4706.357	
4706.790	—.033	+.004	5	4706.761	
4707.658	—.033	+.004	3	4707.629	
4708.426	—.033	+.004	1, n	4708.397	
4709.159	—.033	+.004	1, n	4709.130	
4710.774	—.032	+.004	5	4710.746	
4713.666	—.031	+.004	1	4713.639	
4715.514	—.030	+.004	1	4715.488	
4715.676	—.030	+.004	1	4715.650	
4716.105	—.030	+.004	4	4716.079	
4716.403	—.030	+.004	1	4716.377	
4717.900	—.030	+.004	5	4717.874	
4721.469	—.029	+.004	1	4721.444	
4721.729	—.029	+.004	4	4721.704	
4723.079	—.028	+.004	4	4723.055	
4723.650	—.028	+.004	1, n	4723.626	
4724.099	—.028	+.004	1, n	4724.075	
4728.862	—.026	+.004	1, n	4728.840	
4729.746	—.026	+.904	5	4729.724	
4730.596	—.026	+.004	2	4730.574	
4731.465	—.026	+.004	1	4731.443	
4731.767	—.026	+.004	1	4731.745	
4732.130	—.026	+.004	1	4732.108	
4737.944	—.024	+.004	1	4737.924	
4738.525	—.024	+.004	1	4738.505	
4739.869	—.024	+.004	1, n	4739.849	
4742.838	—.023	+.004	5	4742.819	
4746.845	—.022	+.004	5	4746.827	
4747.331	—.022	+.004	1, n	4747.313	
4748.741	—.022	+.004	5	4748.723	
4751.208	—.021	+.004	5	4751.211	
4751.480	—.021	+.004	1	4751.463	
4751.776	—.021	+.004	5	4751.759	
4752.053	—.021	+.004	1, n	4752.036	
4757.702	—.020	+.004	4	4757.686	
4758.953	—.019	+.004	1	4758.938	
4759.225	—.019	+.004	1, n	4759.210	
4764.238	—.018	+.004	1, n	4764.224	
4765.873	—.018	+.004	1	4765.859	
4766.851	—.017	+.004	7	4766.838	
4769.221	—.017	+.004	1, n	4769.208	
4772.793	—.016	+.004	1	4772.781	

VANADIUM—*continued.*

Wave-length (uncorrected)	Correction 1	Correction 2	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
4773.275	—.016	+.004	1	4773.263	
4776.655	—.015	+.004	5	4776.644	
4781.524	—.014	+.004	1, n	4781.514	
4784.672	—.013	+.004	5	4784.663	
4786.715	—.013	+.004	7	4786.706	
4789.111	—.012	+.004	1	4789.103	
4793.142	—.011	+.004	2	4793.135	
4794.737	—.011	+.004	1, n	4794.730	
4795.300	—.011	+.004	2	4795.293	
4797.125	—.010	+.004	8	4797.119	
4798.157	—.010	+.004	1	4798.151	
4799.216	—.010	+.004	1	4799.210	
4799.978	—.010	+.004	4	4799.972	
4802.378	—.009	+.004	1, n	4802.373	
4803.245	—.009	+.004	1, n	4803.240	
4807.740	—.008	+.004	10	4807.736	
4808.845	—.007	+.004	1, n	4808.842	
4819.225	—.004	+.004	2	4819.225	
4823.030	—.003	+.004	1, n	4823.031	
4827.636	—.002	+.004	10	4827.638	
4829.005	—.001	+.004	1	4829.008	
4829.424	—.001	+.004	1, n	4829.427	
4830.876	—.001	+.004	1, n	4830.879	
4831.832	.000	+.004	8	4831.836	
4832.613	.000	+.004	8	4832.617	
4833.209	.000	+.004	3	4833.213	
4834.001	.000	+.004	1, n	4834.005	
4834.260	.000	+.004	1, n	4834.264	
4835.035	+.001	+.004	1, n	4835.040	
4843.188	+.003	+.004	2	4843.195	
4846.791	+.004	+.004	1, n	4846.799	
4848.995	+.005	+.004	1	4849.004	
4849.253	+.005	+.004	1, n	4849.262	
4849.449	+.005	+.004	1, n	4849.458	
4851.676	+.006	+.004	10	4851.686	
4852.145	+.006	+.004	1, n	4852.155	
4854.104	+.006	+.004	1, n	4854.114	
4855.543	+.007	+.004	1, n	4855.554	
4857.230	+.007	+.004	1, n	4857.241	
4858.798	+.007	+.004	2	4858.809	
4862.789	+.008	+.004	4	4862.801	
4864.930	+.009	+.004	10	4864.943	
4870.320	+.010	+.004	1, n	4870.334	
4871.438	+.011	+.004	3	4871.453	
4873.155	+.011	+.004	1, n	4873.170	
4875.658	+.012	+.004	10	4875.674	
4880.728	+.014	+.004	6	4880.746	
4881.727	+.014	+.004	10	4881.745	
4882.341	+.014	+.004	2	4882.359	
4885.808	+.015	+.004	2	4885.827	

VANADIUM — *continued.*

Wave-length (uncorrected)	Correction 1	Correction 2	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
4886.971	+.015	+.004	2	4886.990	
4890.245	+.016	+.004	1	4890.265	
4891.393	+.017	+.004	2	4891.414	
4891.746	+.017	+.004	3	4891.767	
4894.374	+.018	+.004	3	4894.396	
4900.796	+.020	+.004	3	4900.820	
4904.550	+.021	+.004	5	4904.575	
4905.025	+.021	+.004	3	4905.050	
4907.020	+.022	+.004	1, n	4907.046	
4908.856	+.022	+.004	1	4908.882	
4913.249	+.024	+.004	1, n	4913.277	
4916.413	+.024	+.004	1	4916.436*	
4919.141	+.026	+.004	1, n	4919.171	
4922.514	+.027	+.004	1	4922.543*	
4925.810	+.027	+.004	7	4925.837*	
4932.181	+.030	+.004	3	4932.212	
4933.760	+.031	+.004	1	4933.786*	
5002.502	—.002	+.005	2	5002.505	
5005.790	—.002	+.005	1, n	5005.793	
5014.808	—.002	+.005	4	5014.811	
5047.481	—.002	+.005	1, n	5047.484	
5051.778	—.002	+.005		5051.781	
5060.828	—.002	+.005	1, n	5060.831	
5064.293	—.002	+.005	1	5064.296	
5105.321	—.002	+.005	2	5105.324	
5128.700	.000	+.005	7	5128.705	
5137.765	+.002	+.005	1, n	5137.772	
5138.590	+.002	+.005	4	5138.597	
5139.697	+.002	+.005	2	5139.704	
5148.885	+.003	+.005	4	5148.893	
5159.582	—.049	+.005	2	5159.438	
5159.510	+.005	+.005	2	5159.520	
5165.124	—.049	+.005	1	5165.072*	
5167.013	—.049	+.005	1	5166.961*	
5169.170	—.049	+.005	1	5169.126	
5170.102	—.049	+.005	1	5170.114	
5172.328	—.049	+.005	1, n	5172.284	
5174.702	—.049	+.005	1, n	5174.714	
5176.731	—.049	+.005	1, n	5176.683*	
5177.004	—.049	+.005	1, n	5176.956*	
5178.782	—.049	+.005	1, n	5178.733*	
5179.325	—.049	+.005	1, n	5179.275*	
5180.975	—.049	+.005	1, n	5180.926*	
5182.979	—.049	+.005	1	5182.993	
5183.077	—.049	+.005	1, n	5183.033	
5192.241	—.049	+.005	1	5192.193*	
5193.232	—.049	+.005	5	5193.184*	
5193.843	—.049	+.005	1	5193.795*	
5195.070	—.049	+.005	6	5195.021*	
5195.615	—.049	+.005	2	5195.564*	

*Average of four or more measurements.

VANADIUM—*continued.*

Wave-length (uncorrected)	Correction 1	Correction 2	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
5197.197	+.013	+.005	1, n	5197.215	
	—.049	+.005	1, n	5197.215	
5200.564	—.049	+.005	1, n	5200.520	
5206.839	—.049	+.005	1, n	5206.790*	
5207.892	—.049	+.005	1, n	5207.844*	
5212.377	-.049	+.005	1, n	5212.399	
5213.887	—.048	+.005	1, n	5213.837	
5216.821	—.048	+.005	1	5216.772*	
5225.881	+.022	+.005	3	5225.920	
5233.851	+.026	+.005	2	5233.895	
5234.205	+.026	+.005	7	5234.249	
5240.315	+.029	+.005	2	5240.364	
5241.097	—.047	+.005	3	5241.055	
5258.260	+.043	+.005	1, n	5258.308	
5260.473	+.045	+.005	1, n	5260.527	
5261.188	—.044	+.005	1, n	5261.149	
5271.156	—.042	+.005	1	5271.119	
5317.092	—.030	+.005	1, n	5317.067	
5319.280	—.030	+.005	1, n	5319.255	
5329.511	—.030	+.005	1, n	5329.486	
5330.640	—.029	+.005	1, n	5330.616	
5338.831	—.024	+.005	1, n	5338.812	
5353.633	—.019	+.005	3	5353.619	
5383.654	—.008	+.005	1	5383.651	
5388.537	—.008	+.005	1, n	5388.534	
5402.144	—.001	+.005	5	5402.148	
5415.469	+.005	+.005	5	5415.479	
5418.307	+.006	+.005	1	5418.318	
5424.267	+.009	+.005	2	5424.281	
5434.390	+.015	+.005	4	5434.410	
5437.863	+.017	+.005	1	5437.885	
5443.443	+.018	+.005	1	5443.466	
5445.003	+.023	+.005	1, n	5455.031	
5467.998	+.029	+.005	1, n	5468.032	
5471.528	+.030	+.005	1, n	5471.563	
5487.413	+.037	+.005	1	5487.455	
5488.269	+.038	+.005	4	5488.312	
5490.137	+.039	+.005	1	5490.181	
5505.045	+.047	+.005	1	5505.097	
5506.045	+.047	+.005	1	5506.097	
5507.691	+.048	+.005	4	5507.744	
5508.812	+.048	+.005	1	5508.865	
5511.358	+.050	+.005	1	5511.413	
5515.245	+.051	+.005	1, n	5515.301	
5517.380	+.052	+.005	1. n	5517.437	
5533.988	+.063	+.005	1, n	5534.056	
5535.013	+.064	+.005	1, n	5535.082	
5535.589	+.065	+.005	1, n	5535.659	
5542.880	+.069	+.005	1, n	5542.954	
5545.025	+.071	+.005	1, n	5545.101	

*Average of four or more measurements.

VANADIUM — *continued.*

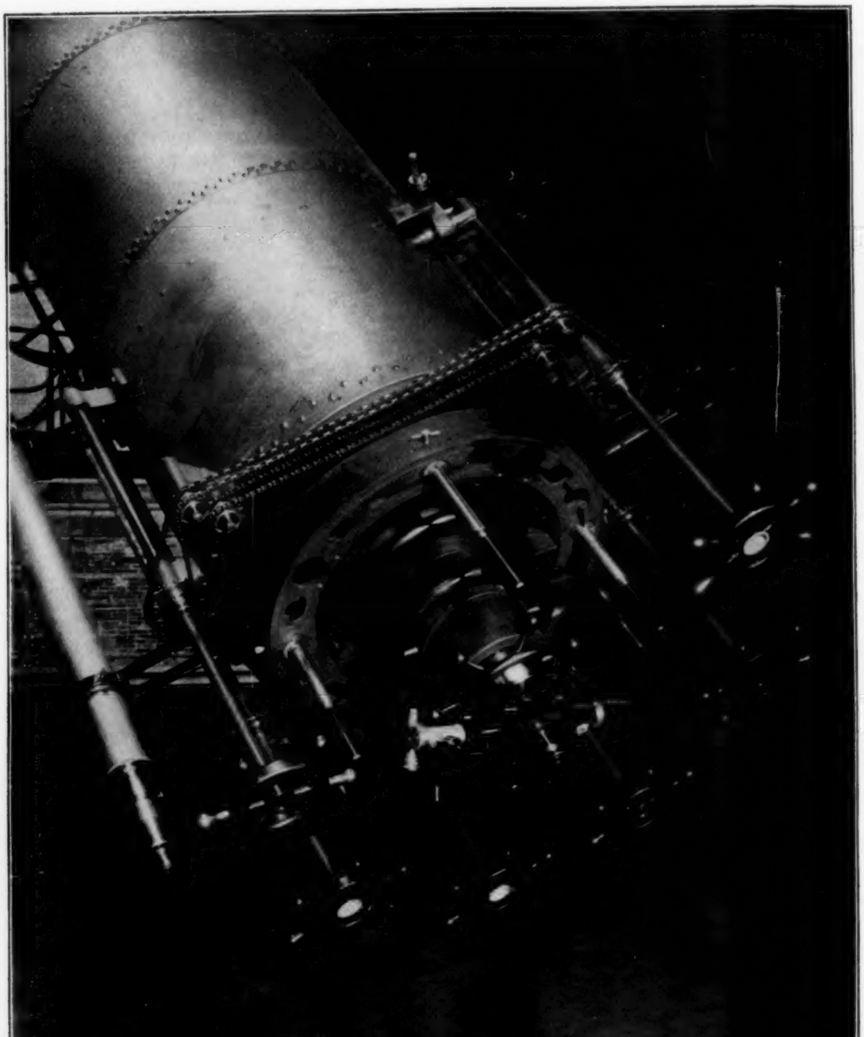
Wave-length (uncorrected)	Correction 1	Correction 2	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
5546.088	+.072	+.005	1	5546.165	
5547.229	+.072	+.005	4	5547.306	
5548.323	+.073	+.005	1, n	5548.401	
5558.908	+.081	+.005	1	5558.995	
5561.898	—.010	+.007	1, n	5561.897*	
5566.065	+.086	+.005	1, n	5566.156	
5567.610	+.087	+.005	1	5567.702	
5576.755	—.010	+.007	1	5576.752	
5584.605	—.010	+.007	1, n	5584.602	
5584.748	—.010	+.007	5	5584.745	
5584.982	—.010	+.007	1, n	5584.979	
5586.235	—.010	+.007	1, n	5586.232	
5588.716	—.010	+.007	1, n	5588.713	
5592.673	—.010	+.007	4	5592.670	
5593.211	—.010	+.007	1, n	5593.208	
5594.734	—.010	+.007	1, n	5594.731	
5598.050	—.010	+.007	1, n	5598.047	
5601.630	—.010	+.007	1	5601.627	
5604.446	—.010	+.007	1	5604.443	
5604.878	—.010	+.007	1	5604.875	
5605.190	—.010	+.007	4	5605.187	
5622.322	—.010	+.007	1	5622.319	
5624.449	—.010	+.007	1	5624.446	
5624.856	—.010	+.007	7	5624.853	
5625.124	—.010	+.007	4	5625.121	
5626.270	—.010	+.007	7	5626.267	
5627.889	—.010	+.007	7	5627.886	
5632.705	—.010	+.007	1	5632.702	
5634.148	—.010	+.007	1	5634.145	
5635.745	—.010	+.007	1	5635.742	
5646.356	—.011	+.007	5	5646.352	
5657.123	—.011	+.007	1	5657.119	
5657.695	—.011	+.007	5	5657.689	
5668.612	—.011	+.007	5	5668.608	
5671.095	—.011	+.007	10	5671.091	
5683.456	—.012	+.007	1, n	5683.451	
5688.003	—.012	+.007	1, n	5687.998	
5698.770	—.012	+.007	1	5698.765	
5703.830	—.012	+.007	10	5703 825	
5707.241	—.012	+.007	10	5707.236	
5709.203	—.012	+.007	1, n	5709.198	
5716.466	—.012	+.007	1, n	5716.461	
5725.886	—.012	+.007	3	5725.881	
5727.294	—.012	+.007	10	5727.289	
5727.905	—.012	+.007	5	5727.900	
5733.340	—.011	+.007	1	5733.336	
5734.258	—.011	+.007	2	5734.254	
5737.314	—.011	+.007	5	5737.310	
5743.678	—.010	+.007	5	5743.675	
5752.988	—.010	+.007	1	5752.985	

*Average of four or more measurements.

VANADIUM — *continued.*

Wave-length (uncorrected)	Correction 1	Correction 2	Intensity and Character	Wave-length (corrected)	Wave-length (Hasselberg)
5761.676	—.009	+.007	1, n	5761.674	
5772.657	—.007	+.007	2	5772.657	
5776.929	—.006	+.007	1, n	5776.930	
5782.846	—.005	+.007	1, n	5782.848	
5783.762	—.005	+.007	1, n	5783.764	
5784.643	—.004	+.007	1	5784.646	
5786.410	—.004	+.007	1	5786.413	

PLATE V.



EYE-END OF THE 40-INCH YERKES TELESCOPE.

Minor Contributions and Notes.

THE NORTHERN DURCHMUSTERUNG.

THE *Durchmusterung* charts of the northern sky are indispensable to every active astronomical observatory, and to every astronomer who wishes to study the fainter stars. Unfortunately, the original edition of this work is exhausted, so that copies can no longer be supplied. A new edition is being prepared by the Bonn Observatory and will be published shortly, provided that subscriptions for a hundred copies, at seventy marks each, are promised before May 1, 1898. The price is very low considering the amount of material furnished. After that date, the price will be raised to one hundred and twenty marks. The Astronomical Conference, held at the dedication of the Yerkes Observatory, appointed the undersigned a committee to aid this project. Orders for copies may be sent to the publishers, Messrs. A. Marcus and E. Weber, Bonn, Germany, or will be transmitted to them by any member of the committee. It is proposed to publish a list of American subscribers, and it is hoped that at least fifty copies will be taken by American astronomers. Since charts deteriorate rapidly by constant use several copies should be taken by each of the larger observatories. The members of the committee have shown their appreciation of the value of this work by ordering twelve copies for use in the institutions under their direction. It is of the greatest importance that the subscription list should be filled as it is probable that in the future many similar enterprises may be undertaken, whose success will depend upon that now attained.

EDWARD C. PICKERING.
J. G. HAGEN, S. J. } Committee.
M. B. SNYDER.

NOTE ON PROFESSOR CAMPBELL'S OBSERVATIONS OF VARIATIONS IN THE INTENSITIES OF THE LINES IN THE ORION NEBULA.

IN the November number of the ASTROPHYSICAL JOURNAL, Professor Campbell attacks, with much indignation, some remarks of mine

criticising his discoveries, contained in an article on Professor Keeler's work on the spectra of nebulæ. Such sensitiveness is somewhat surprising on the part of one who is himself given to severely taking others to task. Further, an astronomer who frequently observes phenomena which others cannot see, and fails to see those which others can, must be prepared to have his opinions contested. If, as Professor Campbell complains, I have only supported my views by a single example, I was only withheld by courteous motives from adding another, namely, the fact that Professor Campbell cannot perceive the lines of aqueous vapor in the spectrum of Mars which were seen by Huggins and Vogel in the first place, and, after Mr. Campbell had called their existence in question, were again seen and identified with certainty by Professor Wilsing and myself. Whether such instances will be multiplied in the future remains to be seen.

That Professor Campbell should call in the testimony of other astronomers to support his results is quite natural, but I find it strange that he should select for this purpose two gentlemen whose names are as yet quite unknown as skilled observers. In fact, Messrs. Aitken and Wright, in their excess of youthful zeal, betray their inexperience by remarking that they found it "easy," and "very easy," to verify the variation in the relative brightness of the nebular lines—a feat which a Huggins found almost beyond his powers. Professor Schaeberle also used a similar expression. I regret, however, that the tone adopted by this gentleman (who is in no way concerned in the discussion) renders it impossible for me to take any further notice of his remarks.

Professor Campbell compels me now to detail the grounds upon which the conclusions given in my brief criticism were based. To begin with, I must designate the method of observation adopted by Mr. Campbell as unfavorable for the attainment of good results. This is due to the fact that he used the great refractor, an instrument not very well designed for the object in view, since, owing to the great linear extent of the focal image, only a small portion of the nebula can be seen through the slit at once, and therefore estimates of variations, if such existed, in the relative brightness of the nebular lines, could only be made by a series of successive observations involving a difficult memory exercise.

In view of this I must adhere to my former statement, that my observations were made "under very favorable circumstances." The instrument I used was the photographic refractor, whose ratio of aper-

ture to focal length is as 1 to 10, so that the surface intensity of illumination of the image is three or four times as strong as in the case of the great Lick refractor. The focal length being 3.4 meters, the diameter of the focal image, while quite sufficient to enable the details of the nebula to be recognized, is yet less than the length of the slit of the spectroscope. Thus different parts of the nebula can be examined at once. The brightest regions of the nebula are to be recognized by the corresponding apparent widenings or knots upon the spectrum lines, and if the relative brightness be constant, these knots must appear in the same proportion to the fainter portions for each of the three nebular lines. The determination of relative brightness can thus be made by direct comparison, and I think that this gives the method a great advantage over Professor Campbell's. By moving the slit all parts of the nebula can, of course, be brought into the field of view and seen in conjunction with other parts. I have with profit used a rather high-power eyepiece in these experiments, the light-grasping power rendering this possible; and thus I had the same advantage as regards working with a large image that would have been given by the use of a more powerful telescope.

Professor Campbell's result practically amounts to this: That the line appeared to him, with reference to the two other nebular lines, brighter in the fainter regions than in the brighter regions of the nebula. I do not doubt for a moment that Professor Campbell honestly thinks he saw this as he says, but I emphatically dispute his interpretation, namely, that the appearance was based upon a real variation of relative intensity. On the contrary, I maintain that "so far as a matter of this kind can be established," the relative intensity of the three nebular lines is constant over the Orion nebula.

The whole appearance recorded by Professor Campbell is nothing more nor less than the "Purkinje phenomenon." The human eye possesses the physiological peculiarity that its maximum sensibility to light, which in the case of strong illumination lies in the yellow, shifts, as the illumination decreases, towards the more refrangible end of the spectrum, and finally, as the limit of visibility is approached, lies very near the F or $H\beta$ line.

I have gone more fully into this subject in another paper, which will be published at the same time with these remarks.[1] The results given there for an extreme case can easily be applied to the present question.

[1] See p. 231.

May I be allowed to add a few words? Professor Campbell challenges me to publish, "without delay," my estimations of the relative intensities of the nebular lines in the region of the star Bond No. 734. I regret that I am unable to comply with this severe demand, as Nature has not endowed me with the power of measuring relative intensities by use of the eye alone, without any photometric apparatus. I could arrange the intensities according to an arbitrary scale, but I cannot say how many times one line is brighter than another. Until now I have always believed, on the ground of physiological investigations, that this was a task beyond the power of any human being, but after the wonderful agreement achieved by the Lick observers, I am better informed.

May I be permitted to suggest that Professor Campbell might derive some advantage from the study of Physiological Optics?[1]

J. SCHEINER.

ASTROPHYSICAL OBSERVATORY,
Potsdam, January 1898.

A PROVISIONAL LIST OF PHOTOMETRIC UNITS.[2]

The insuperable difficulty of measuring photometric quantities in mechanical units renders more or less unsatisfactory any system of units we may adopt for dealing with luminous energy.

For the sake, however, of intelligent communication with each other, some such system is indispensable.

We have accordingly adopted the following as representing the best scientific usage.

In practice we shall seldom, if ever, have occasion to deal with the total radiation which any source of energy emits.

For the present we are engaged in transmitting only that portion of the total radiant energy which is capable of affecting the retina of the normal eye.

[1] The editors would suggest that further discussion of this question be postponed until an appeal to purely photographic methods shall have removed it from the province of physiological optics. For while Professor Campbell does not appear to have taken the Purkinje phenomenon into consideration, Professor Scheiner seems to have overlooked the variations in the apparent relative intensities of the lines which he himself insists must arise from this source. The publication of a photograph of the spectrum, taken with a slit extending from the Trapezium to the star Bond No. 734, should set all doubts at rest.

[2] Prepared for use in the Laboratory of the American Luxfer Prism Company.

To this fraction of the total radiant energy we shall give the name

LUMINOUS ENERGY.

Concerning this term the following two points are to be borne in mind: (1) that while it is a practical impossibility to go into the laboratory and measure just what fraction of the total radiant energy exists in the form of luminous energy, yet this fraction is a perfectly definite quantity; (2) "Luminous energy" is equivalent to "light" only when the latter is used in the narrow sense so as not to include actinic and thermal effects.

These conventions fixed, we are ready to consider the following photometric quantities.

I. ***Intensity*** of a point-source (or of a source which is sufficiently small compared with its distance to be treated as a point-source) is defined as ***the amount of luminous energy emitted per second.***

The word "intensity" is used in a great variety of senses in scientific terminology. If, therefore, any ambiguity should at any time arise as to its exact meaning, it may be modified to read "luminous intensity," which is never employed in any sense except as above defined.

Concerning the nature of intensity in general, it need only be added that it does not represent a quantity of energy such as that contained in a storage cell or in a coiled spring. It is a rate of flow of energy, a ratio between a quantity of energy and a time. The product, intensity by time, is luminous energy; and this product determines the amount of one's gas or electric-light bill.

Since it is impracticable to determine intensity in mechanical measure the following unit is suggested:

Unit of intensity is defined as ***the intensity of a Hefner lamp in a horizontal direction, the dimensions[1] of the Hefner lamp being those prescribed by the Reichsanstalt at Berlin.***

Name: This unit is called "one candle."

Symbol: for $\begin{cases} \text{intensity, } J. \\ \text{candle power, } c.\ p. \end{cases}$

Much has been said both *pro* and *con* concerning the Hefner lamp. That the flame is red, that it is not perfectly steady and that its intensity varies with the composition of the atmosphere in which it burns must be freely admitted. Since, however, it burns a fuel of definite

[1] For these dimensions, see Palaz, *Industrial Photometry*, pp. 136–143.

chemical composition, since the purity of this fuel is easily tested, since there is no charring of the wick, since the dimensions of the lamp are so chosen that slight deviations from the prescribed size produce a minimum disturbance, and since this standard is highly recommended by the *Reichsanstalt* and the *Committee of the American Institute of Electric Engineers*,[1] its adoption is here suggested.

The quantity which we shall next consider, viz., *Luminous Current*, is the only one out of the entire list for which there is no practical use in the laboratory. Its introduction, however, leads to great simplification in the definitions of the three succeeding quantities, enabling us to avoid the use of π or any of its multiples, concerning which so many pages have been written in the case of the electrical units.

II. *Luminous Current* is defined as *the rate at which luminous energy is emitted by a point-source through a solid angle of one steradian.*

Unit: The luminous current of one candle, *i. e.*, of one Hefner lamp.

Name: "Lumen." Proposed by L. Weber.

Symbol: for $\left\{ \begin{array}{l} \text{luminous current, } \phi \\ \text{lumen, } lm \end{array} \right.$

It is evident that if a point-source radiated uniformly in all directions its intensity would be 4π times its luminous current, *i. e.*,

$$J = 4\pi\phi.$$

But for an element of surface which radiates from one side only as, for instance, a diffusing screen,

$$J = 2\pi\phi.$$

III. *Illumination* is defined as *the ratio of the luminous current to the area upon which it falls.*

This is the same as saying that the illumination is measured by the number of lumens per square centimeter at the point in question. The numerical value of the illumination at any point in a room measures, in general, the success with which that part of the room is lighted. It must not be forgotten, however, that of two equal illuminations, one produced by rays from one direction only, the other by rays from many directions, the latter is as a rule much more effective.

Illumination is a property of a surface at a point; and is determined only by the area and the light immediately incident upon it, independently of the source.

It is evident, however, that in case of a point-source the illumi-

[1] *Transactions Amer. Inst. Elec. Engineers*, **13**, 1896.

nation varies inversely as the square of the distance between the point and surface; in case of a linear source the illumination varies inversely as the distance; in case of a plane source, of practically infinite extent, such as the sky, the illumination is entirely independent of the distance separating the source and the illuminated surface.

Concerning the illumination produced by the sky, two facts are always to be borne in mind, viz., (1) that, for all photometric purposes, the sky is a surface at an infinite distance; and (2) that in practice the sky is nearly always diaphragmed: it may be by the cell of a lens, it may be by a window frame, it may be by an ordinary diaphragm. Consequently the natural unit in which to measure the amount of the sky producing illumination at any point is one steradian subtended by that point.

Unit of illumination is one lumen per square centimeter.

Name: "Lux."

Symbol: for $\begin{cases} \text{illumination, } E \\ \text{Lux, } lx \end{cases}$

IV. ***Brightness*** is defined as ***the luminous current leaving unit area of apparent surface.***

The fundamental distinction between brightness and illumination is that, in the former, the surface is considered as the origin of a luminous current; while in the latter, the surface is considered as the recipient of the luminous current.

The Violle standard is essentially a standard of brightness, becoming a standard of intensity only when used with a diaphragm of measured area. We can assign to any portion of the sky a definite brightness only when we imagine the sky to be a surface at a definite distance. The illumination which any portion of the sky produces at a point, however, is quite independent of the imaginary distance of the sky, being a function of the solid angle subtended by the portion of the sky in question.

Unit of brightness is that brightness which yields one lumen per square centimeter of apparent surface.

Name: Lumen per square centimeter.

Symbol: for $\begin{cases} \text{brightness, } B \\ \text{unit of brightness, } lm\ per\ cm^2 \end{cases}$

Not infrequently one is called upon to consider both the intensity of a source and the length of time for which it is available. An incandescent lamp during the first and second halves of its life does not

furnish equal quantities of light to the user. The quantity of sky light available varies tremendously with the weather, with the time of day, and with the season of the year. In comparing the sky light available in January with that at our disposal in July we shall need, therefore, the following unit :

V. *Quantity of light* is defined as *the product of the luminous current by the time it flows.*

Unit quantity of light is one lumen for one second.

Name : . . . .

Symbol : . . . .

DIFFUSION.

Mascart has shown how we may, with a high degree of approximation, compute the increase of illumination produced within any closed space by the light which is "diffusely returned" from the enclosing walls. For this purpose Mascart denotes by Q the amount of light emitted by the illuminating source per second, and by N, a constant, which ranges from, say, 0.04 for black velvet to 0.82 for very white paper.[1] Then the amount of light incident upon the walls of the space per second is W, where

$$W = Q\frac{1}{1-N}.$$

I venture to think that this factor $\frac{1}{1-N}$ is of more importance than is generally admitted, and suggest the adoption of the following definition for N:

VI. *Diffusion constant* is defined as the *ratio of the brightness to the illumination at any point on a surface.*

The numerical value of this constant represents the fraction of the incident light at any point which is diffusely reflected by the surface through unit solid angle.

If we denote the diffusion constant by N, then in the system of units which we have employed above

$$N = \frac{\text{brightness}}{\text{illumination}}.$$

Sometimes, however, brightness is defined differently from the manner in which it has been defined above, viz., to denote the

[1] For an excellent discussion of this whole subject, as well as a good series of experimental determinations of N, see SUMPNER : *Phil. Mag.*, February 1893.

intensity (instead of the luminous current) of unit area. In this case the diffusion constant becomes the ratio between 2π brightness and the illumination. That is, its defining equation becomes

$$N = 2\frac{\pi \text{ brightness}}{\text{illumination}} .$$

For, maintaining our definitions of illuminations and diffusion constant, as above given, it is evident that the numerical value of N will vary inversely as the numerical value of the unit of brightness; and, farther, that the unit of brightness depends upon the defining equation of brightness, if consistency is to be preserved.

VII. ***Luminosity.***

In all that has been said above, it has been tacitly assumed that the quantities under consideration (brightness, illumination, etc.) refer to luminous energy of the same quality, *i. e.*, to lights of the same composition or colors of the same hue. But in practice it becomes very frequently necessary to compare lights of different color.

In general, indeed, the brightness of the wall of a room has a different hue from that of the illumination which produces this brightness.

Accordingly it becomes necessary for us to define just what we mean when we say that a certain room illuminated by blue light is just as brilliantly lighted as a certain other room which is illuminated by red light. The ease with which one can read a newspaper depends not only upon the intensity of the light with which it is illuminated, but very largely upon the quality of this light. That particular property of any color which determines its value as an illuminant is called its "luminosity."

Thus, for the normal eye, yellow light is much more useful than red of the same intensity; and red light, in turn, is a more powerful aid to distinct vision than blue of the same intensity.

It only remains now to give to "luminosity" a quantitative definition. This is done by the use of a principle discovered by Rood (*Amer. Jour. Sci.* **46** (3), 173, 1893), viz., that when a normal eye is allowed to perceive a colored surface for a short interval of time, say a fraction of a second, the intensity of the sensation is independent of the hue, and depends only upon the luminosity. If a circular cardboard disk be covered, one-half with gray, the other half with a colored pigment, the two halves will have equal luminosities when on rotation all sense of flickering disappears. It is thus found that each color

in the spectrum requires a definite gray to "match" it. The amount of white in the gray semicircle which matches any given color is a measure of the luminosity of this color. In this connection it may be added that any color is completely defined only when we know the following three things about it, viz.:

1. Its "hue," *i. e.*, the wave-length of the light in the solar spectrum which most nearly matches it.
2. Its "luminosity."
3. Its dilution, sometimes called "purity," sometimes called "saturation," *i. e.*, the amount of white light which is mixed with the pure color producing it.

HENRY CREW.

THE TOTAL SOLAR ECLIPSE.

FROM the preliminary reports in *Nature*, the *Observatory* and elsewhere it appears that the total eclipse of January 22 was observed throughout India with remarkable success. An exceptional number of skilled observers, supplied with the most complete instrumental equipments hitherto employed for such a purpose, were scattered along the line of totality. In pleasing contrast with the general disappointment which attended the observations of the last eclipse, come the uniform reports of perfect weather and valuable results. Encouraged by Mr. Shackleton's signal success in photographing the spectrum of the "flash" in 1896, several parties have given this work the principal place in their programme of observations. At Viziadrug Mr. Fowler and Dr. W. J. S. Lockyer, using prismatic cameras having in the first instance two 45° prisms of 6 inches aperture and in the second a single 45° prism of 9 inches aperture, secured some sixty photographs of the spectrum of the Sun's limb. Many of these were taken in such a way as to furnish a complete spectroscopic history covering a period of ten seconds. Sir Norman Lockyer, who had charge of this party, estimates that some of the photographs show as many as a thousand lines. In addition to the lines of the reversing layer the photographs show several monochromatic images of the corona. In the spectrum of the flash the two-prism camera gave about double the number of lines obtained by Mr. Shackleton at Novaya Zemla.

Of perhaps even greater importance are the photographs of the spectrum of the "flash" made at Pulgaon with slit spectroscopes by Captain Hills. As the spectroscopes employed for this purpose are of

high dispersion, the photographs should serve admirably for wave-length determinations. Captain Hills also succeeded in photographing the spectrum of the corona to 4′ from the Sun's limb. Beyond this point, however, nothing was shown, and it is therefore not surprising, though greatly to be regretted, that Mr. Newall did not succeed in his attempt to determine the motion of the corona in the line of sight at a distance of 8′ from the limb. Professor Campbell had also intended to photograph the spectrum of the corona with a view to measuring its rotation, and as the brief report cabled by him to the Lick Observatory expresses satisfaction with his results it is to be hoped that he has been as successful in this direction as in others. In any event he seems to have photographed the spectrum of the reversing layer, for which purpose he had provided a slit spectroscope. As the "flash" spectrum was also successfully photographed by Professor Naegamvala and Mr. Evershed with objective spectroscopes, material has been secured for an extensive study of the spectrum of the Sun's limb.

The spectrum of the corona received less attention, but photographs were obtained by Mr. Newall and others. The green coronal ring was observed visually by Mr. Newall with a grating spectroscope, and Mr. Maunder endeavored to trace out the regions giving 1474 light, using for this purpose an opera-glass with a direct vision prism on one eyepiece. Mr. Maunder states in an article in *Knowledge* that the corona was too faint as seen in this way to render possible a detailed examination of the distribution of the light of this wave-length. As no rifts were seen, however, the observations as far as they go confirm the result obtained many years ago by Tennant.

The form of the corona was photographed by scores of observers, provided with the greatest variety of instruments. These ranged from the kinematographs of the Rev. J. M. Bacon and Lord Graham, through hand cameras giving a solar image about a millimeter in diameter up to objectives of great focal length, giving images four or five inches in diameter. Professor Campbell employed in this work the apparatus so successfully used by Professor Schaeberle in South America in 1893. Mr. Burckhalter's device for simultaneously giving suitable exposures to both the inner and outer corona is said to have produced good results, though the region near the Sun was over-exposed. The form of the corona, a cut of which is given in the *Observatory* for March, is similar to that of 1896. It is important to

add that for the first time in some years Professor Turner has obtained photographs which clearly show the polarization of the corona in at least one streamer.

From this brief outline of some of the principal results obtained it is evident that we may confidently expect the reduction of the photographs to add in no small degree to our knowledge of the Sun.

G. E. H.

OCCULTATION OF 26 ARIETIS OBSERVED PHOTOGRAPHICALLY.[1]

THE disappearance of a bright star when occulted by the Moon is always a striking phenomenon. There is no celestial event whose time is susceptible of more precise determination. For many years various plans have been suggested, both here and elsewhere, by which this time could be determined with greater accuracy than by ordinary visual observation. In fact, the apparatus for photographing the eclipses of Jupiter's satellites, used here for several years, was devised in part for this purpose.

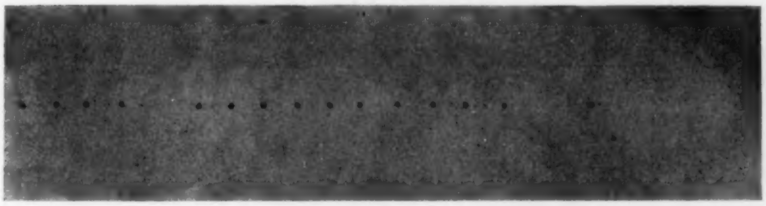
On February 25, 1898, Mr. Edward S. King for the first time succeeded in satisfactorily photographing the occultation of a star. The apparatus used was an improved form of that constructed for photographing the eclipses of Jupiter's satellites, and described in the ASTROPHYSICAL JOURNAL **1**, 146. The plate was moved automatically every second by means of an electro-magnet. A motion of about $0^{cm}.03$ was given to the plate whenever the circuit was closed, and of an equal amount when it was opened. Connecting the apparatus with the standard clock, Frodsham 1327, two images alternately faint and bright were obtained every second. As the faint images are three magnitudes fainter than the bright images, the ratio of the durations was about one to sixteen, so that the absolute durations were $0^{s}.06$ and $0^{s}.94$. It is here assumed that, as the times of exposure were very short, the chemical action was proportional to the time. This assumption is verified by actual measurement.

Considering only the images taken during the minute following $6^{h}\ 35^{m}\ 0^{s}$, the bright images of 26 Arietis, as shown below, are equally intense including that having an exposure lasting from $50^{s}.06$ to $51^{s}.00$. Since this image appears to be as bright as the others, the light of the

[1] *Harvard College Observatory Circular*, No. 26.

star could not have begun to diminish much before the time $51^s.00$. If the star had disappeared suddenly at $50^s.9$ the last image would be at least 0.12 of a magnitude fainter than the others, an amount readily measurable. The next image is apparently invisible. Had the disappearance taken place at $51^s.06$ the image would appear, and would

40^s 50^s



Occultation of 26 Arietis.

be as bright as the other faint images. A slight darkening of the film is perceptible near the position the next image would have had, with an intensity nearly equal to that of the fainter images. If this were due to the star, it would denote that the latter suddenly disappeared at about $51^s.12$. The absence of the preceding image would indicate a more gradual disappearance. In any case, the time is fixed at $51^s.1$, to within one-tenth of a second. As the clock was $2^m\ 19^s.4$ fast, not including armature time, the corresponding Greenwich Mean Time is $12^h\ 54^m\ 26^s.5$. By using shorter exposures the uncertainty in the time of disappearance can doubtless be greatly reduced, especially in the case of the brighter stars. Since satisfactory images of 26 Arietis, magnitude 6.1, were obtained in $0^s.06$, it is probable that occultations of stars as faint as the ninth magnitude can be observed photographically.

Measures were next made of the intensity of the last five images of 26 Arietis, to see if there was any diminution in light due to the absorption of a lunar atmosphere. The distances of these images from the Moon's limb were $1''.8$, $1''.4$, $1''.0$, $0''.6$, and $0''.2$, respectively. The corresponding changes in light, expressed in magnitudes as compared with ten more distant images, were $+0.03$, $+0.03$, -0.02, $+0.03$, and -0.02. A positive sign denotes that an image was fainter than those at a greater distance from the Moon. From this it appears that

no diminution in light was perceptible. No correction need be applied to any of the above calculations for the diameter of the star's disc, since, assuming its intrinsic brightness equal to that of the Sun, its time of disappearance would be only $0^s.002$ (*Proc. Amer. Acad.*, **16**, 1).

In this connection it is interesting to note that the determination photographically of the position of the Moon, by means of a star about to be occulted, was one of the subjects investigated by Professor G. P. Bond forty years ago. He obtained a number of photographs of the Moon and α Virginis shortly before the occultation of the latter on June 2, 1857. EDWARD C. PICKERING.

March 3, 1898.

COMPARISON STARS FOR VARIABLES.[1]

APPLICATIONS have recently been received from several observers of variable stars for photometric magnitudes of the comparison stars used by them. The measurements described below are available and will be furnished in advance of publication to any astronomer who desires to use them. Sequences of comparison stars have been selected for about one hundred variable stars of long period. Examples of sixteen of these sequences will be found in the pamphlet entitled *Variable Stars of Long Period*, 4°, Cambridge, 1891. Each of the comparison stars brighter than the tenth magnitude has been measured on at least three nights with the meridian photometer. About five stars of each sequence, from the eleventh to the thirteenth magnitude, have been measured on two nights with the photometer having achromatic prisms. (ASTROPHYSICAL JOURNAL, **2**, p. 89.) The intervals between the adjacent stars in the sequences have been estimated in grades on three or more nights by Mr. Wendell with the fifteen-inch telescope, and by Mr. Reed with the six-inch telescope. From these estimates and measures a system of magnitudes has been derived in which the accidental errors are very small, and in which the scale for faint as well as for bright stars is nearly the same in all parts of the sky. This scale, which is that of the meridian photometer, is substantially the same as that of the Potsdam Observatory, and of the *Uranometria Oxoniensis*, the differences not exceeding one or two-tenths of a magnitude. Observations are completed of the variable stars T

[1] *Harvard College Observatory Circular*, No. 27.

Andromedae, T Cassiopeiae, R Andromedae, S Ceti, S Cassiopeiae, R Piscium, R Arietis, T Persei, *o* Ceti, S Persei, R Ceti, U Ceti, R Tauri, S Tauri, R Aurigae, U Orionis, R Lyncis, R Geminorum, S Canis Minoris, R Cancri, S Hydrae, T Hydrae, R Ursae Majoris, X Virginis, R Comae, T Virginis, Y Virginis, T Ursae Majoris, R Virginis, S Ursae Majoris, U Virginis, R Hydrae, S Bootis, R Camelopardali, U Herculis, W Herculis, R Ursae Minoris, R Draconis, χ Cygni, S Cygni, R Delphini, U Cygni, V Cygni, T Aquarii, T Cephei, S Cephei, SS Cygni, S Aquarii, R Pegasi, S Pegasi, R Aquarii, and R Cassiopeiae, and it is expected that the others will be finished in a few months. An attempt is made at this Observatory to compare, by Argelander's method, the brightness of each of these variable stars once a month. If astronomers elsewhere would reduce their observations to the same scale of magnitudes, a uniformity in results would be obtained which is now unfortunately lacking. These measures are now being extended to other variable stars of long period, and it is hoped that later all stars of this class may be observed regularly and according to a uniform system.

Photometric magnitudes, determined with the meridian photometer, can also be furnished of many other stars brighter than the tenth magnitude, besides those mentioned above. Volumes XIV, XXIII, XXIV, and XXXIV of the *Annals* give the magnitudes of all stars from the North to the South Pole, brighter than the sixth magnitude, besides many fainter stars generally distributed in zones at regular intervals of five degrees in declination. Later observations have been made of all stars of the magnitude 7.5 and brighter, north of the declination $-40°$. A redetermination of the brightness of all the stars in the *Harvard Photometry* is included in this work.

MISCELLANEOUS NOTES.

The variability of a star in the constellation Aquila, whose position is in R. A. $19^h\ 33^m.3$, Dec. $+\ 11°\ 29'$ (1900), has recently been announced by the Rev. T. D. Anderson (*A. N.*, **145**, 79). Measures of fifty-seven photographs give the maximum brightness 9.2, minimum <12.9. The variations can be closely represented by the formula, *J. D.* 2,411,550 + 330 *E*.

The Rev. T. E. Espin, in *Wolsingham Observatory Circular*, No. 45, calls attention to a red star of the eighth magnitude in R. A. $8^h\ 12^m\ 16^s$, Dec. $+\ 32°\ 19'$ (1855), not contained in the *Durchmusterung*.

This star appears on thirty photographs taken from December 3, 1889, to March 5, 1898, and no variation in light exceeding two or three tenths of a magnitude is indicated. The individual results differ from their mean by $\pm$ 0.13 mag.

EDWARD C. PICKERING.

MARCH 7, 1898.

THE NEW DIRECTOR OF THE LICK OBSERVATORY.

IT is a great pleasure to be able to announce, just as the JOURNAL is going to press, that Professor Keeler has decided to accept his recent appointment as Director of the Lick Observatory. The writer takes the liberty of severing his editorial relations for a moment, in order that he may offer his heartiest congratulations to both Professor Keeler and the Lick Observatory on this important event. In spite of a meager equipment, used with difficulty in the smokiest region in the United States, Professor Keeler has obtained results of the highest order since leaving Mt. Hamilton seven years ago. He will now have at his disposal the perfect instruments employed in his well-known researches on the motion of the nebulæ in the line of sight. It may be permitted one whose acquaintance with Professor Keeler is not confined to a knowledge of his scientific work, to say that the Regents of the University of California have chosen wisely in selecting a new director. The future will show that the interests of the Lick Observatory have been placed in competent hands.

GEORGE E. HALE.

Reviews.

Die Photometrie der Gestirne, von PROFESSOR DR. G. MÜLLER, Observator am Königlichen Astrophysikalischen Observatorium zu Potsdam. (Pp. x+556, 81 figures. Leipzig: Engelmann, 1897).

THE oldest branch of astrophysics, celestial photometry, although prolific in periodical literature, has been the subject of singularly few books. The works of Bouguer, Lambert, Seidel, and Zöllner have successively recorded progress, but until now no complete manual of this important branch has been published. The present work, thus practically the first in the field, deals with the subject in so comprehensive, thorough, and satisfactory a manner that it is difficult to speak of it without enthusiasm.

The book is divided into three parts: I. The elements of theoretical celestial photometry (pp. 1–144); II. Photometric apparatus (pp. 145–304); III. The results of photometric observations of the heavens (pp. 305–510).

The first chapter gives a clear mathematical exposition of the fundamental laws of photometry, with an important section on physiological intensity and Fechner's (or Weber's) psycho-physical law, which expresses the fact that the subjective impression is proportional to the logarithm of the objective brightness. Other sections take up the illumination of surfaces from luminous point sources and from surface sources; and Lambert's theorem that the quantity of light is proportional to the cosine of the angle at which it emanates, for which a proof by Lommel, rigorous for self-luminous, opaque objects, is given. Diffuse reflection is considered, and it is shown that for substances so reflecting Lambert's theorem has no validity. Bouguer's theory of reflection is taken up, and its extension, with limitations, by Seeliger is explained; and finally the development is given of the "Lommel-Seeliger" law of illumination, which shows the dependence of the amount of light reflected upon the absorptive and diffusive power in the interior of the substance and upon the angles of incidence and emergence in the form

$$\frac{\cos i \cos \epsilon}{\cos i + \lambda \cos \epsilon},$$

(λ being the ratio between the absorptive power on entering and on leaving the reflecting substance). The difference between the two laws of reflection is illustrated by taking the simple case of vertical incidence ($i = 0$) upon a plane surface. According to Lambert's theory the apparent brightness would be the same when viewed from all angles (ϵ), while the theory of Lommel and Seeliger indicates that when viewed from a point (nearly) in its own plane the apparent brightness would be but half of that when viewed perpendicularly. Seeliger's somewhat complicated mathematical developments are followed until the final expression is obtained for the light received by the eye from the surface element ds, namely,

$$Q = \frac{1}{4\pi k} \mu L\, ds \frac{\cos i \cos \epsilon}{\cos i + \cos \epsilon} \left[1 + \frac{\mu}{2k} \cos \epsilon\, lg\left(\frac{1 + \cos \epsilon}{\cos \epsilon}\right) + \frac{\mu}{2k} \cos i\, lg\left(\frac{1 + \cos i}{\cos i}\right)\right]$$

where k is the coefficient of absorption of the substance, μ its diffusive power, and L is the quantity of light from the source received at the unit volume of surface. From the symmetry of the equation with respect to i and ϵ, it would follow that the brightness should be independent of the azimuth — the same whether observer and source were on the same side or on opposite sides of the normal to the surface. But observations by Seeliger and by Messerschmitt show that the brightness is greatest when eye and source are opposite each other, *i. e.*, differ in azimuth by 180°. Hence even this formula is not accurate, and it can be regarded as only approximate.

The definition of *albedo* is next taken up in the light of these recent researches. The common use of the term is only correct where Lambert's cosine law obtains, for there the percentage of light reflected back to the eye (relative brightness) is the same for all angles of incidence; but for a law of illumination that involves both the angle of incidence and emergence, the albedo differs for each incidence and the term loses its significance. Seeliger has therefore given an expression to define the albedo, which after integration is independent of the angle of incidence, viz.,

$$A' = 2\pi C \int_0^{\frac{\pi}{2}} \tan i \, di \int_0^{\frac{\pi}{2}} f(i, \epsilon) \sin \epsilon \, d\epsilon,$$

wherein for $f(i, \epsilon)$ may be substituted the expression for any law of reflection.

For $f(i, \epsilon) = \dfrac{\cos i \cos \epsilon}{\cos i + \lambda \cos \epsilon}$ (Lommel-Seeliger),

the albedo after integration becomes

$$A' = \frac{\pi C}{\lambda} \left\{ 1 - \lambda \, ln \, \lambda + \frac{\lambda^2 - 1}{\lambda} \, ln \, (1 + \lambda) \right\}$$

in which C and λ are constants peculiar to each substance and depending upon its power of absorption and reflection, and *ln* signifies the natural logarithm.

In chapter II these fundamental principles are applied to the most important problems of celestial photometry: the illumination of planets and satellites; the illumination of a system of small bodies; the eclipses of Jupiter's satellites. Parallel developments of the necessary formulæ are given according to the three laws of illumination upon which they may be based, namely,

$$\text{Lambert's}: \; dq_1 = \Gamma_1 \, ds \cos i \cos \epsilon$$

$$\text{Lommel-Seeliger}: \; dq_2 = \Gamma_2 \, ds \frac{\cos i \cos \epsilon}{\cos i + \lambda \cos \epsilon}$$

$$\text{Euler's}: \; dq_3 = \Gamma_3 \, ds \cos i,$$

in which dq is the quantity of light emitted at angle ϵ from the surface element ds, which receives its light under an angle i; the constants depending upon the intensity of the incident light, and upon the power of reflection, scattering (or "diffusion"), and absorption of the substance concerned.

The first section thus treats of the calculation of the amount of light we receive at different phases of planets, and of the determination of albedo; of the distribution of light on a planet's disk; of the illumination of satellites; of the calculation of the "Earth-shine" on the Moon. It is a decided merit of this work that it reproduces in so full a manner the important theoretical investigations of Seeliger, which are rather inaccessible to most observatories because of their publication in the Proceedings of the Bavarian Academy.

The second section of this chapter gives at considerable length Seeliger's theory of the illumination of Saturn's rings, by means of which the brightness of the system can be reduced to that for vanished rings. The eclipses of Jupiter's satellites occupy ten pages, and it is shown that the advantage of reducing all measures to the time of half brightness, as originally suggested by Cornu, holds good for any law of illumination. The third chapter of Part I is devoted to the extinction of light in the Earth's atmosphere, taking up in successive sections the theories of Lambert, Bouguer, Laplace, and Maurer, and then comparing the theories with observations, with an outcome favorable to the theory of Laplace. As a practical average value of the transmission coefficient Müller recommends 0.835.

Part II of the work gives in 160 pages a full description of the instruments employed in celestial photometry, classified according to their principle and illustrated by some forty admirable engravings. Both the theory and the practical working of the various instruments are clearly set forth, with valuable comments suggested by the large experience of the author. Spectral-photometers occupy a chapter, and actinometers, the bolometer, and other objective modes of measuring radiations are more briefly treated.

In Part III the photometric observations of the Sun, Moon, planets and satellites, comets, nebulæ and stars are successively considered, and the broad practical experience of the author is made available to the reader in a most useful way. The results of the various observers are subjected to a careful and judicial criticism. A special value of this part lies in the suggestiveness of the treatment, for the lines in which future work is needed are no less plainly brought out than are the records of past observations. Especially prominent is the need of more accurate photometry of the Sun, and, as the author states, "here a rich and promising field of activity remains open for the astrophysicist." For the ratio of brightness of the Sun and full Moon the author does not adopt the value of Zöllner usually employed in text-books (618,000), but prefers the mean of Zöllner's two results and Bond's (470,980), which gives 569,500. The wide range of these determinations sufficiently illustrates the need of more work in this direction. As the values of the albedo of the planets differ considerably from those current in many text-books, it may be worth while to give the author's determinations here, according to the definitions of Lambert and Seeliger :

	Lambert	Seeliger		Lambert	Seeliger
Moon	0.129	0.172	Uranus	0.604	0.805
Mercury	0.140	0.187	Neptune	0.521	0.694
Venus	0.758	1.010	Jup.-Sat. I	0.412	0.550
Mars	0.220	0.293	Jup.-Sat. II	0.489	0.652
Jupiter	0.616	0.821	Jup.-Sat. III	0.259	0.346
Saturn	0.721	0.961	Jup.-Sat. IV	0.118	0.157

Especially valuable sections are those dealing with stellar photometry, entitled photometric catalogues, variable stars, spectral-photometric observations of stars, and the photographic brightness of stars. In view of the great number of variable stars, the discussion in that section is necessarily somewhat limited. Tables are given for reduction of phase and of atmospheric extinction, followed by an extensive bibliography. As pecuniary reasons will presumably forbid an English translation of this work, we must most strongly recommend it for the libraries of teachers as well as of astronomers.

E. B. F.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation,

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Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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The ASTROPHYSICAL JOURNAL is published monthly except in July and September. The annual subscription price for the United States, Canada, and Mexico is $4.00; for other countries in the Postal Union it is 18 shillings. Correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago, University Press Division, Chicago, Ill.*

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